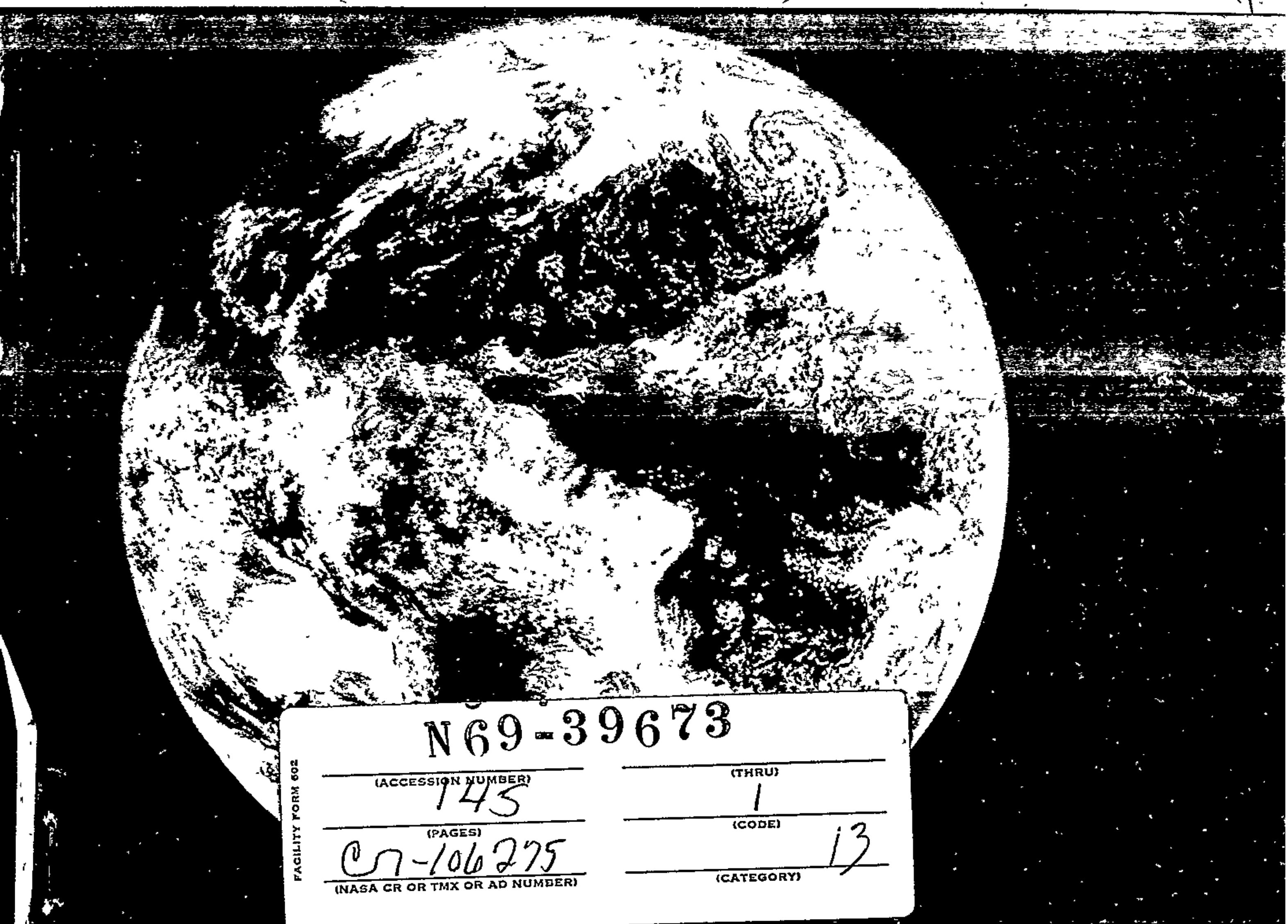
NASA CONTRACT
NSR 47-003-010

TELLURIAN RESOURCES INVENTORY AND DEVELOPMENT

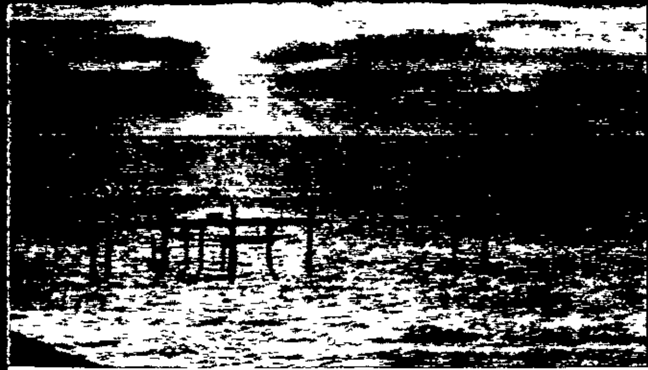


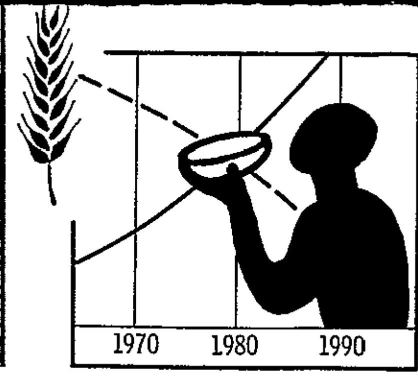
NASA Langley Research Center
and Old Dominion University

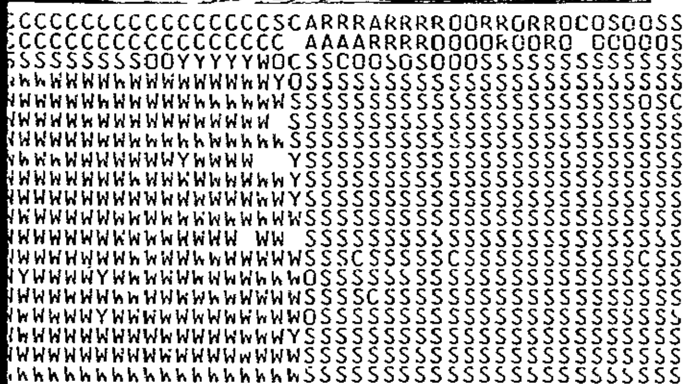
1969

TRIAD

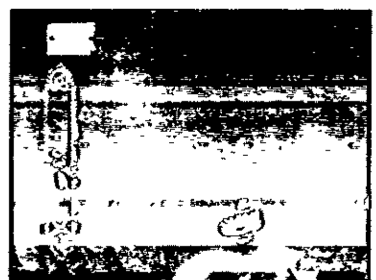
The cover photograph, taken November 18, 1967 by ATS-III while stationed over the Equator at 47° W longitude, shows nearly the entire western hemisphere of our planet Earth, and represents the environment in which we must live. The necessary knowledge for the wise use of this whole is dealt with in this study.

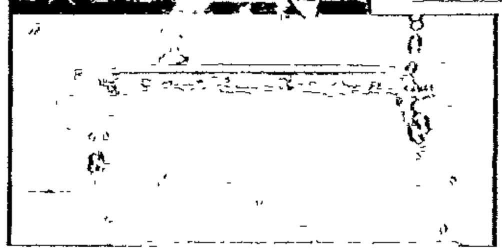


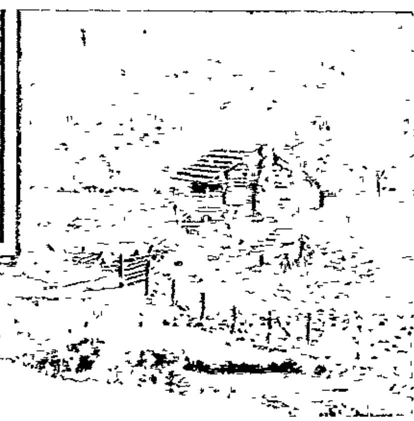


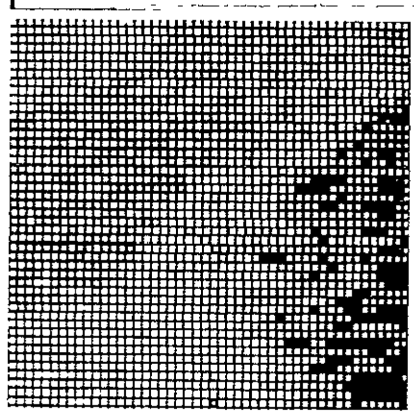


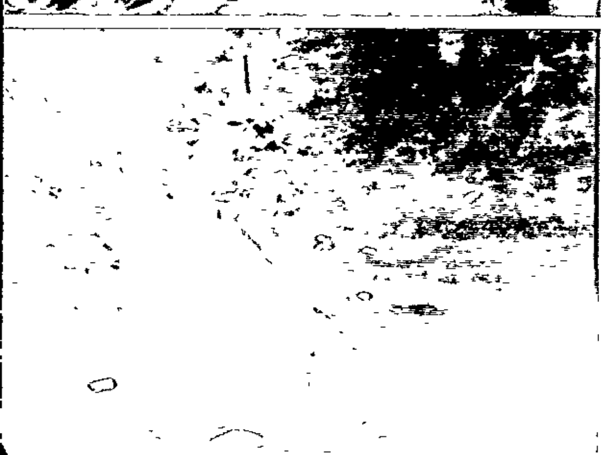
MODERN MAN FACES A HOST OF SUCH SERIOUS AND INTERRELATED PROBLEMS INVOLVING THE EARTH'S RESOURCES AS HUNGER, AIR AND WATER POLLUTION, AND DEPLETION OF RAW MATERIALS. BADLY NEEDED HELP MAY SOON BE ON THE WAY THROUGH AN OPERATIONAL EARTH RESOURCE SURVEY SYSTEM INVOLVING SATELLITES, AIRCRAFT AND GROUND SENSORS.

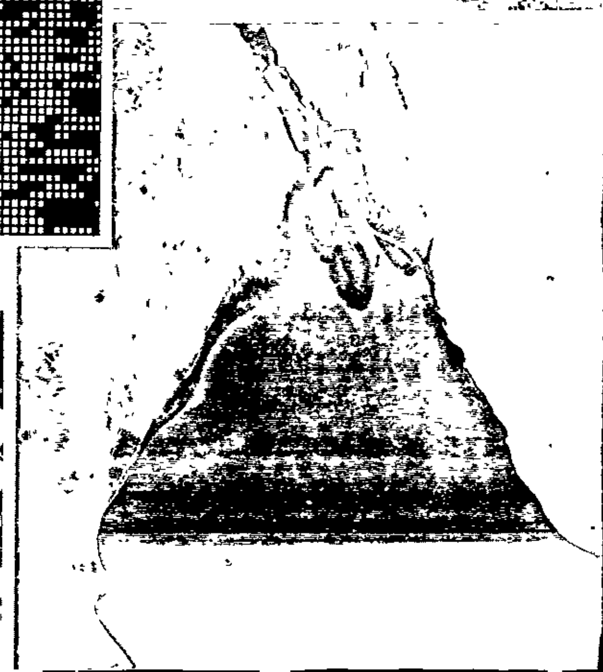












TRIAD

PRELIMINARY DESIGN OF AN OPERATIONAL EARTH RESOURCES SURVEY SYSTEM

Editor-in-Chief: Keith R. Carver, Ph.D.

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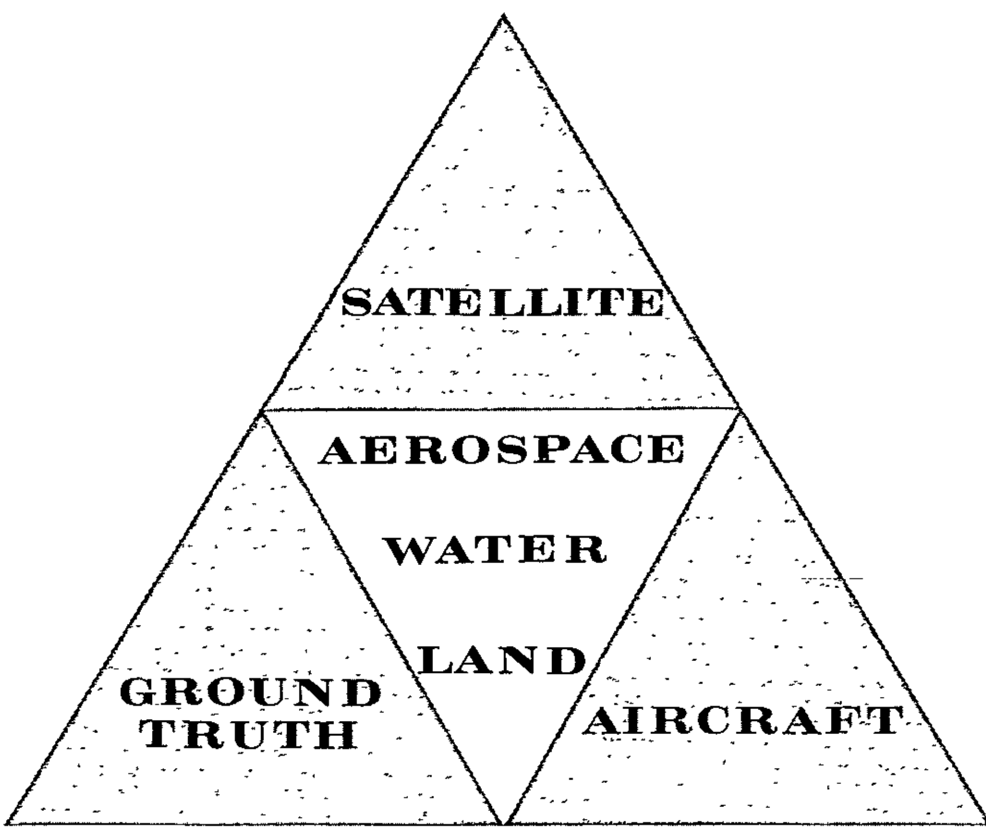

1969 SUMMER
FACULTY FELLOWSHIP PROGRAM
IN ENGINEERING SYSTEMS DESIGN

ASEE - NASA LANGLEY RESEARCH CENTER
OLD DOMINION UNIVERSITY RESEARCH FOUNDATION

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ABSTRACT

The results of a multidisciplinary system design study directed towards the definition of a preliminary design concept for an operational earth resources survey program are presented. Phases of the study include: 1) evaluation of societal needs in relation to basic resources of food, raw materials, power and conservation, 2) technological, political, and social feasibility, and 3) description of an operational system.

The analysis of needs is approached without regard to possible technology limitations. World problems of a socio-economic nature pertinent to the survival and progress of civilization are summarized. Also, the disciplines of Agronomy, Geology, Geography, Oceanography, Hydrology, and others, are surveyed from a user-agency point of view. Specific data needs are presented that existing agencies have expressed a desire to acquire. Parameters to be measured, minimum resolution requirements, and most likely sensors are indicated for each need.

The feasibility of the three main features that should be included in the conceptual definition of an operational earth resource survey program is examined. These features arise naturally from consideration of specific data needs and are: 1) data acquisition, 2) data handling, and 3) earth resource survey administration. Each of the three areas are investigated to determine possible parameters and subsystem arrangements that might be employed to meet system requirements.

Finally, a discussion is given of a total concept for an operational earth resource survey system. This includes types of data to be acquired, specifications of sensors and platforms, data processing and distribution, and illustration of an administrative structure for carrying out an operational program.

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FOREWORD

This document describes the results of the 1969 ASEE-NASA Summer Faculty Program in Systems Design conducted at the Langley Research Center during the period June 9 through August 22. The program was supported by the National Aeronautics and Space Administration through contract to the Old Dominion Research Foundation of Old Dominion University.

The objectives of the systems design program included the following:

(1) To provide a useful study of a broadly based problem that required the coordinated efforts of a multidisciplinary team.

(2) To provide a framework for communication and collaboration between academic personnel and research scientists and engineers in governmental agencies and private industry.

(3) To generate experience and foster interest for participation in and development of systems design programs and courses at the home institutions of the participants.

The summer study activity was directed towards the definition of a preliminary design concept for an operational earth resources survey system. In broad terms, the earth resources include food, raw materials, power and conservation. The charge given to the summer faculty group was to define an operational system that could respond to societal needs in relation to earth resources in order to promote development of a well-ordered civilization.

The problem of earth resource needs and procedures for their inventory and development is far-reaching and complex and requires input from a large number of discipline areas. The faculty group selected for the study at the Langley Research Center was composed of representatives from twelve (12) scientific disciplines including the political, sociological, economic, geological, chemical, biological, botanical, and the engineering sciences. This discipline group comprised an effective multidisciplinary team that was very well suited for study of the earth resources problem.

In addition to the combined talents of the participants, the study benefited from numerous lecturers and consultants from a number of governmental agencies, universities and private industries. It is a pleasure to acknowledge the cooperation extended by the Departments of Agriculture and Interior, and the United States Naval Oceanographic Office in addition to the NASA Headquarters Offices and the Langley Research Center technical specialists.

Appreciation is expressed for the many courtesies and the comfortable atmosphere provided by the Co-Directors of the ASEE-NASA Summer Institute, Drs. Gene Goglia and John Duberg. The support and patience extended by Messrs. Walter Hixon and Patrick Clark is also warmly acknowledged.

Mr. Robert N. Parker of the Langley Research Center served as Technical Advisor to the study project from its inception to its conclusion. For his devoted attention to the project and to the individual requests of the participants, the 1969 ASEE-NASA Summer Faculty expresses its deepest gratitude.

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*Mr. Cordle participated in the program under support from the Shell Aid Foundation.

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	H. R. Compton	ASMD
	J. F. McNulty	FVSD
2.0 Reliability	H. H. Ricker, Jr.,	FID
	A. H. Lindler	FID
	H. T. Thornton, Jr.	FVSD
3.0 Launch Vehicle Performance	J. E. Canady, Jr.	AMPD
	C. A. Brown, Jr.	AMPD
	E. J. Wolfe	FVSD
4.0 Space Vehicle Design Criteria	G. W. Jones, Jr.	SVDCO
4.1 Dynamic Loads	H. T. Thornton, Jr.	FVSD
4.2 Meteoroid Environment	W. E. Bresette	AMPD
	W. H. Kinard	AMPD
	T. N. Bartron	FVSD
4.3 Radiation Environment	J. P. Mugler, Jr.	AMPD
	H. D. Hendricks	AMPD
5.0 Sensors		
5.1 Passive Imagers	W. T. Suit	ASMD
5.1.1 Film	F. O. Huck	FID
	R. J. Exton	IRD
	R. R. Adams	IRD
5:1.2 TV	C. D. Lytle	FID
5.1.2 Line Scanners	A. Jalink, Jr.	FID
5.2 Active Imagers	R. L. Kenimer	FID
5.2.1 Radar		
5.2.2 Laser	L. P. Kopia	FID
	J. H. Goad, Jr.	IRD
5.3 Radiometers/ Spectrophotometers		
5.3.1 Microwave	Dr. H. J. C. Blume	FID
	W. L. Jones, Jr.	FID
5.3.2 Optical	R. B. Spiers, Jr.	FID
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	T. B. McKee	AMPD
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TECHNICAL AREA	SPECIALIST Name	Division
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5.4.1 Radar/ Microwave	W. T. Bundick	FID
5.4.2 Lasers	D. E. McIver, Jr.	FID
	S. L. Ocheltree	IRD
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5.5.1 Magnetometer	Dr. D. E. Bowker	AMPD
5.5.2 Gravimeter		
5.6 In Situ Sensors (Interrogate)	C. A. Gurtler	FID
5.6.1 Oceano-graphic	Dr. S. L. Seaton	IRD
5.6.2 Hydrographic		
5.6.3 Earth Physics (Crustal Motion)	Dr. D. E. Bowker	AMPD
5.6.4 Environmental Quality		
6.0 Data Management		
6.1 Tracking and Data Acquisition		
6.1.1 STADAN	J. N. Daniel	FID
6.1.2 Data Relay Satellites	H. M. Lawrence	FID
6.2 Telecommunications and Frequency Allocation	H. M. Lawrence	FID
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6.3.1 Data Storage	N. D. Murray	FID
6.3.2 Data Compression	E. M. Bracalente	FID
	C. D. Lytle	FID
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9.0 Electrical Power	J. L. Patterson	FID
	J. Bene	FID
	R. C. Wells	FVSD

TECHNICAL AREA	SPECIALIST Name	Division
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	W. S. Slemp	AMPD
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	C. E. Kirby	FVSD
12.0 Structures and Shielding	Dr. J. J. Singh	IRD
	K. S. Bush	FVSD
13.0 Recoverable Payloads	J. C. McFall, Jr.	AMPD
	H. Elksnin	FVSD

VISITING LECTURERS AND CONSULTANTS

Date	Visitor	Subject or Discipline
June 10, 1969	Carl F. Zorowski N. C. State University	Systems Design Philosophy
June 11, 1969	William A. Fischer U. S. Geological Survey	Earth Resource Observation System Program
	Charles J. Robinove U. S. Geological Survey	Rationale for an Earth Resource Observation System
June 12, 1969	W. Douglas Carter U. S. Geological Survey	Geological Applications of an Earth-Resource Observation System
	Morris Deutsch U. S. Geological Survey	Hydrologic Applications Using ERTS-1
June 13, 1969	Gerald Levy Old Dominion University	Ecology
June 17, 1969	Robert O. Piland NASA-Manned Spacecraft Center	Earth Resource Aircraft Program
June 18, 1969	John G. Barmby Illinois Institute of Technology Research Institute	Earth Resource Mission Analysis
June 19, 1969	Theodore E. George NASA-Headquarters	Earth Resource Technology Satellite Program
June 20, 1969	Dave W. Keller Bruce Bachofer Mort Goldman General Electric–Missile and Space Division	Earth Resource Technology Systems
June 24, 1969	Robert R. Stephens NASA-Headquarters	STADAN System and Data Relay Satellite

Date	Visitor	Subject or Discipline
June 25, 1969	George L. Huebner Texas A & M University	Oceanographic Remote Sensing
June 26, 1969	Gene A. Vacca NASA-Headquarters	Technology Implications of an Earth Resource Survey System
June 27, 1969	L. E. Mumbower IBM—Federal Systems Division	Earth Resource Program Ground Data Processing
July 1, 1969	John G. Barmby Illinois Institute of Technology Research Institute	Political Implications of an Earth Resource Survey System
July 9, 1969	Robert N. Colwell University of California at Berkeley	Evaluation of Biological and Natural Resources by Remote Sensing Techniques
July 10, 1969	A. B. Park U. S. Department of Agriculture	Agriculture and Forestry
July 11, 1969	John W. Sherman, III U. S. Naval Oceanographic Office	Spacecraft Oceanography
July 14, 1969	R. A. Summers NASA-Headquarters	Systems Studies for Earth Resource Survey
July 23, 1969	Paul M. Maughan Bureau of Commercial Fisheries	Fishery Oceanography and Marine Resources
July 24, 1969	S. S. Viglione McDonnell-Douglas Corporation Missile and Space Systems Division	Pattern Recognition Systems
July 30, 1969	Edwin J. Istvan Communications Satellite Corporation	Management of an Earth Resources Survey System

Date	Visitor	Subject or Discipline
July 30, 1969	Herbert B. Quinn, Jr. Joseph Vitalle NASA-Headquarters D. E. Cunningham Miami University	Role of the University in Multidisciplinary Research
August 7, 1969	Charles R. Smith RCA Defense Electronic Products Astro Electronics Division	Specific Applications of Earth Resource Data
August 11, 1969	Robert D. Ellermeier University of Kansas	Radar Imagery

LIST OF GROUP ORGANIZATIONS AND LEADERS

The study activity was organized through selection of group leaders and delineation of subgroup and individual responsibility throughout the several phases of the program. The chronological phases were needs analysis, feasibility study, and preliminary design. A multidisciplinary mix was maintained in group composition with communication and liaison being provided between groups by meetings of the group leaders. During feasibility and preliminary design phases at least one member in each group was also a member of a second group thus providing additional channels of communication.

Group Assignments for Needs Analysis

Group I was to investigate social and economic problems pertinent to the survival and progress of civilization in relation to total earth resources.

K. R. Carver
S. R. Cordle
J. D. Gibson
F. C. Haas
P. F. Homsher
P. C. Heckert, Chairman
C. E. Jarvis
B. Jump
J. D. Lowther
A. H. Stocks

Group II was to investigate the scientific disciplines for useful applications and identification of measurement potential.

W. G. Batte
H. O. Goller
T. A. Gosink
G. T. Hageseth
W. J. Hanna
G. E. Lamp
D. E. McKee, Chairman
J. D. Morgan
H. G. Mueller
P. A. Volz

Group Assignments for Feasibility Study

The objective of the Feasibility Study was to examine alternative approaches and arrangements of various subsystems in order to select a plan for more detailed study that would best satisfy system requirements revealed in the Needs Analysis.

Administration

S. R. Cordle
H. O. Goller
F. C. Haas
C. E. Jarvis
J. D. Lowther
H. G. Mueller, Chairman
A. H. Stocks
P. A. Volz

Data Handling System

W. G. Batte
G. T. Hageseth, Chairman
W. J. Hanna
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J. D. Lowther

Data Acquisition

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J. D. Gibson
H. O. Goller
T. A. Gosink
W. J. Hanna
D. E. McKee, Chairman
J. D. Morgan

Needs and Uses

J. D. Gibson
P. C. Heckert
P. J. Homsher
B. Jump, Chairman
P. A. Volz

Group Assignments for Preliminary Design

The Preliminary Design was concerned with selection and definition of an operational earth resources survey system.

Administration

S. R. Cordle
H. O. Goller
F. C. Haas
C. E. Jarvis, Chairman
J. D. Lowther
H. G. Mueller
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P. A. Volz

Data Handling System

W. G. Batte
G. T. Hageseth, Chairman
W. J. Hanna
P. C. Heckert
P. J. Homsher
G. E. Lamp
J. D. Lowther

Data Acquisition

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K. R. Carver
J. D. Gibson
H. O. Goller
T. A. Gosink
W. J. Hanna
D. E. McKee, Chairman
J. D. Morgan

Needs and Uses

J. D. Gibson
P. C. Heckert
P. J. Homsher
B. Jump, Chairman
P. A. Volz

Editorial Group

To ensure that the final report would be completed on time and be representative of the entire study period the following editorial group was established at the end of the second week.

K. R. Carver (Editor-in-Chief)
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C. E. Jarvis
J. D. Lowther
F. L. Moreadith

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Organized Visit and Tour Old Dominion University Norfolk, Virginia	Faculty Fellows

PREFACE

Since the material resources of our planet are obviously limited and are undergoing depletion, it has become evident that an operational plan for their inventory must be implemented along with an orderly program for their development and use. Such a broad plan for the sustenance and improvement of civilization in relation to the earth's resources has been given the acrynom TRIAD, standing for Tellurian Resources Inventory and Development. The word tellurian is derived from Tellus, who in Roman mythology was the goddess of the earth.

The purpose of this document is thus to describe a preliminary design for an operational system for the survey of the earth's resources. This preliminary design concept has evolved naturally from the consideration of a number of pressing human needs requiring specific earth resources data on the one hand, and a consideration of our present and projected remote sensing technology on the other. Therefore, this report is addressed to the problem of describing the major features which should characterize an operational system for surveying certain of the earth's resources.

After the introductory chapter, an exposition of basic human problems and needs is made in Chapter II. Chapter III discusses the underlying rationale and philosophy which has been used in attempting to answer the need of certain specific data by use of remote sensor technology via an operational system. The various features which might characterize data acquisition, data handling and administrative functions, are discussed and compared. Following these considerations, Chapter IV outlines the major features of a suggested operational earth resources survey system. The epilogue reviews the report and projects into the future.

CHAPTER I

INTRODUCTION

1.1 **BACKGROUND** The need for coordination of the various activities devoted to developing the capability for inventory and development of earth resources has been recognized. This recognition has led to a current research and development program under the title of Earth Resource Technology Satellites (ERTS) that is coordinated by NASA. The ERTS project consists of a series of satellites that will be synthesized from existing spacecraft systems and subsystems. The process for selection of the experimental sensors to be included in the payloads represents a significant advancement in interagency cooperation on scientific investigations.

The first-generation earth resource technology satellite is expected to be launched during 1972. While the initial payloads will involve evaluation of a restricted set of sensors with limited capabilities, the data obtained and the experience gained in working with new modes of acquisition and data analysis are expected to provide some of the information that would be required for implementation of an operational earth resource survey system. The operational system would thus be expected to follow the initial technology systems and would involve a coordinated data acquisition scheme that would include satellite, aircraft, and ground based sensors. Specific data requested by the users would be acquired on a routine basis. Additional features of an operational system would include a data management arrangement and an administrative structure for supervising the several functions of the organization.

1.2 **EMPHASIS OF STUDY** The emphasis of this study has been placed on developing a preliminary design concept for an operational earth resource survey system that would be initiated after sufficient sensor technology has been developed by the ERTS program. Preliminary design, as a stage in the total design process, includes specification of all the requisite gross features required to define the total system. The preliminary design concept follows from an analysis of alternative approaches and arrangements that could respond to the needs established for the system and thereby specifies a plan for more detailed study from which would evolve a detailed operational design.

It should be borne in mind that a number of proposals concerned with earth resources, other than the concept discussed above, have been generated recently. Prominent among these proposals is an arrangement for a general purpose, manned orbiting laboratory that would incorporate provision for collection of earth resource data with other subsystems. The need and feasibility of employing a manned satellite system or general purpose laboratory for collection of earth resource data has not been considered in the study reported on herein.

1.3 **OVERVIEW** This report gives the results of a multidiciplinary systems study directed towards the definition of a preliminary design concept for an operational earth resources survey program. The study was organized in three main phases: 1) study and review of needs, 2) feasibility study, 3) a synthesis procedure leading to the preliminary design concept. In this document the needs study that was accomplished is summarized. A companion, supplemental document devoted entirely to societal needs in relation to earth resources has been prepared separately.*

*See Needs Analysis Supplement for supporting material.

Following a discussion of the basic study and review of societal needs in relation to earth resources, further deliberations set forth three main features that should be included in the conceptual definition of an operational earth resources survey program to satisfy specific needs. These characteristics follow from sensing of physical phenomena to data use and are: 1) data acquisition, 2) data handling, and 3) earth resources survey administration. Each of these three areas are examined carefully in order to expose all parameters and subsystem arrangements that could be profitably exploited to meet specific data needs.

The principal effort concerned with data acquisition is directed at sensor evaluation and selection, orbit considerations, platform requirements, and communications and data transmission. The central theme here is to identify the gross features of the subsystems rather than specific details. For example, the features examined with regard to sensors include parameters to be measured, platform and/or orbital requirements, power requirements, weight, data format and rate, and resolution and sensitivity.

In the area of data handling, attention is given to data collection control, data processing and formatting, data bank requirements, data receiving stations, on-board data analysis, data distribution, and the data users. Particular emphasis is placed on providing a structure for responding to a request for specific kinds of data.

It is recognized that the total panorama of societal needs and data requests related to earth resources could overtax whatever system man might devise and a methodology to be employed for analyzing the merits of each data need case is discussed. A number of basic criteria are delineated and include such check points as: 1) clear economic benefits, 2) apparent important contributions to knowledge concerning preservation of ecological balances, and 3) probably payoffs in terms of promoting "peaceful and good" interpersonal, national, and international relations. Additional criteria are set forth and a set of leading candidates that are appropriate for inclusion in an earth resource survey and inventory program are discussed.

One of the most complex problems discussed is the "design" of an administrative system which could properly manage an earth resources survey system. Answers to three basic questions are provided. The questions are: What kind of institution should it be—governmental, international, private, or a combination? If it is governmental or international, where does it fit into existing structures? How is it to be funded?

The assumptions made about data handling and acquisition are enumerated. Considerable attention is given to the rationale employed in selecting the criteria against which the system is to be measured.

Finally, a discussion is given of a total concept for an earth resources survey system. This includes the type of data to be acquired, specifications of sensors and platforms, data processing and distribution, and illustration of an administrative structure for carrying out an operational earth resources survey program. The administrative organization discussed has been given the title Earth Resources Survey Administration—ERSA.

In summary, this report represents the total systems concept that evolved from the efforts of a multidisciplinary team concerned with the survey and proper use of the resources of the earth that are necessary for the survival of mankind. In order to sustain and improve civilization, use would be made of satellites, aircraft, and ground truth in observation, survey, and coordination of land, sea, and air data, and for these reasons the concept developed has been entitled Tellurian Resources Inventory and Development—TRIAD.

CHAPTER II.

STUDY AND REVIEW OF BASIC NEEDS

2.1 **PREAMBLE** Since we are proposing a system to collect additional data, we ought to consider for a moment just how well society is equipped to utilize data in existence. Such an exercise leads to rather pessimistic conclusions. For example, we have abundant data indicating that a sizeable minority in the United States suffers from malnutrition and we also know that many of our farmers are paid not to produce to their capacity—and this seemingly irrational behavior has continued for several decades. Certainly no one can conclude that data inadequacies are the cause of the problem or the barrier to solution. Likewise, we know that at least two countries have the technical capability literally to destroy the world as we know it and only the unrealistically optimistic can translate current proposals to implement ABM and MIRV programs as indicative of progress in harnessing such potential destruction. Though more difficult to quantify in a brief statement, it is equally clear that we are misusing such resources as land, air, and water at the same time that we have the technical capability to curtail such misuse.

The point of the preceding is that the bulk of the critical problems facing mankind—problems about which an earth resources survey system seeks data—are manmade. Few of our most critical probelms are too complex for our technological capabilities—if only our social, economic and political institutions can be adapted as required.

So we are left with the question of how more and better quality data can be expected to contribute to solutions. Of course, we recognize that there are certain kinds of information that cannot be collected for technical or economic reasons without the advanced data collection system that we are designing. But however valuable such an enterprise may be, we see its potential as resting on society's ability to adjust and modernize its institutions so as to respond appropriately to a technologically-induced changing environment. And the sad fact that comes forth from our ever growing store of data is that necessary social change seems to lag far behind technological change [1].

One conclusion that we derive from these observations is that in order for man to survive and at least to maintain his quality of life he must develop a mechanism by which he can anticipate his long-range problems and devise solutions. It seems clear that "we can no longer afford to let things 'work themselves out,' to bumble through. The consequences from bumbling into disasters will be too great and the chances of getting out of them while preserving a democratic ethos too small to risk such an approach" [2, p. 66].

We do not propose to develop here a sketch of what the long-range planning mechanism should look like nor do we explore here how to overcome the psychological trauma and near catatonia displayed by many at the mere mention of the word planning*. But it is important to recognize that "good planning requires sophisticated theory and data about society and appropriate means for applying both, and all three preconditions will take time to attain—during which time we are very likely to be in very serious trouble. The result of this will be more turmoil and complexity and, thereby, still greater need for more and better long-range planning" [2, p. 67]. Thus it is our hope that at the same time that we devote additional energy to collecting data, by whatever method, we recognize that our existing theories of complex social processes are so crude that "we know relatively little about what to measure or observe . . ." [2, p. 10].

*But we do maintain that planning is quite compatible with an essentially democratic form of government. For our view of the problems that must be dealt with in moving toward a system of planning, see Reference 1, esp. Chapter 4.

2.2 **AN APPRAISAL OF NEEDS*** Because mankind's survival is so dependent upon earth's resources, it is important that the utilization of these resources be arranged in a manner best able to provide benefits to the greatest number with a minimum of waste or destruction, with proper attention being given to the possibility of replenishment of certain resources in short supply or the discovery of new substitutes for them. This, in turn, points up the need of securing as complete an inventory of the earth's resources as can be obtained, global in scope if possible, and marshalling all available means of acquiring the data required for such an undertaking.

For far too many of the world's population, the problem of survival is an acute one, with hunger, poverty, disease, and an environment that is subject to too little human control taking a heavy toll annually. For a good number of people in an affluent society like ours, the problem of survival does not seem to be so much of a worry, but, even here, there is no assurance of survival against certain hazards that seem to increase even as abundance increases. Examples are air and water pollution, heavy concentrations of traffic, and increased risks of man-made disasters.

It has been said that a little knowledge is a dangerous thing and it might be added that even a great deal of knowledge is a thing of little use unless it is put to use. This is one of the more challenging problems of our time: putting to better use the great wealth of knowledge we already have and are constantly expanding. Too many of the world's problems remain unresolved because mankind has either been unable or unwilling to apply his knowledge to resolving them soon enough and effectively enough to prevent them from reaching major proportions. Too often, the focus has been on remedial rather than preventive action and, as a consequence, it is very apt to be a case of too little and too late. One can only hope that there still remains time for mankind to learn how to make better use of his knowledge before he destroys himself.

What does mankind need for survival? In the long run, perhaps, mankind's survival upon this earth may necessitate adaptations so drastic that they would be neither recognizable nor acceptable by people living in the present generation. Be that as it may, for the foreseeable future at least, we know that mankind now requires certain things in his diet, in the air he breathes, the water he drinks, and in the environment generally in which he lives that are almost indispensable to the perpetuation of his particular species of life on earth. It is possible to list general and specific needs of mankind but to classify them into any meaningful order of priority is not, for priorities change as the enrivonment and man's mastery of it or his failure to cope with it changes. What starts out as a minor environmental problem has potentialities of disaster proportions if neglected while dramatic technological advances may reduce another major environmental problem to one of minor significance.

No society's problems are ever exactly the same as those of its predecessors or of those societies which succeed it. For example, pollution or contamination of the environment can hardly be deemed much of a problem in an area of vast open spaces with a very sparse population. Yet, in some communities today, it is a very serious problem becoming increasingly worse. Smoke, smog, dust, and toxic fumes irritate eyes and respiratory systems and increase the incidence of communicable diseases and respiratory infections, while offensive sights, odors, and noises combine to make living or working in crowded urban areas even more unpleasant. And now a new element has been added to the danger from pollution of air, water, and soil: the danger of contamination of earth from space or other planets and of space or other planets from earth.

*See Needs Analysis Supplement for supporting material.

Similar observations might be made about other human needs. Energy of one kind or another is required to run our homes, our farms, our industries, our communication, transportation, and power systems on land and sea, in the air, and now in space. Traditionally, we have relied primarily on such fossil fuels as wood, coal, oil, and gas for fuel or power. At present, power resources seem adequate but increased consumer demands may eventually deplete supplies to a level that will necessitate more and more reliance on such things as nuclear energy. Power itself is neutral. It can be used constructively to explore the universe, to place man on the moon, to reduce the burden of his labor in many ways, and to transform the environment for the betterment of man generally. On the other hand, it can be used to kill and to destroy, to ruin the environment, and to hasten the disappearance of man from the face of the earth unless it is subject to restraints designed to channel it into peaceful applications and to safeguard human life. The choice is ours.

Man's need to travel, first on land and sea, and more recently in air and space, has been met by continuously expanding technological improvements in the methods of doing so. Problems have also expanded as land, sea, and air space have become more congested with traffic and the possibility of collision rises proportionately. There is greater need for traffic routing and control, standardization of signaling systems, frequent reporting of location, direction, and rate of speed of aircraft and ships.

Much of this latter need relates directly to the need of communication. Here, too, great progress has been made and numerous problems have developed. A more efficient communications network is needed for ships and aircraft, especially for search and rescue operations involving land and sea accidents or as an aid to navigation in avoiding accidents. There will be an increasing need for more careful allocation of radio and TV frequency channels also.

Not only is there a need for conservation of the resources on which we depend for our fuel and power, but for conservation of many other of the world's resources as well. Potable water, arable land, fish and game, timber, minerals, and other physical materials important to man's livelihood, well-being, or recreation are examples. More information is needed about the techniques of forest conservation, wildlife management, mineral detection as well as water run-off patterns and soil erosion. Utilization of this information and the enforcement of regulations is even more important.

Among events generally considered to be in the disaster category are: avalanches, cave-ins, collapse of man-made structures, collisions and wrecks involving many people, droughts, earthquakes, epidemics, explosions, famines, fires, floods, hurricanes, landslides, large scale pollution of soil, water, or air, including radiation, locust invasions, revolutions, riots, tidal waves, tornadoes, volcanic eruptions, and wars. Some are due to natural phenomena while others may be traced to causes for which man is primarily responsible.

Although we do not always know the exact cause of all disasters and may not be able to foresee all of the direct and indirect consequences likely to result nor prevent them from happening, we do know that some potential disasters can be and have been prevented by timely advance warnings and appropriate preventive actions. Some that have not been prevented might have been if more data had been available at the proper time and place concerning their nature, causes, and likely tendencies. In the case of disasters not subject to any effective preventive action, such data and its use could at least greatly reduce the extent or area of disaster, helping to minimize the damage done, the loss of life, and making possible the better planning of such things as evacuation, rescue, and relief action in communities hit by disasters.

There is a real need for greater protection against the danger of both natural and man-made disasters and any data that can effectively be used to assist us in their early detection, prediction, possible prevention, containment, or preparation for and recovery from them would be of inestimable value when one considers the potential value of a single human life that may be saved. Present facilities for dealing with disasters are defective or inadequate for a variety of reasons, especially in their inability to detect and report disasters promptly and accurately on a global basis and even the use of aircraft still leaves many remote areas on land and sea and in the air unmonitored at all or not on anything like a continuous basis.

The problems of world population density and world hunger are rather closely related for the projected expansion of population requires a corresponding expansion of food supply to keep pace with it. The prospects so far are not at all encouraging. There is a definite need of further efforts being made to curb the population explosion, especially in those areas least able to support large populations under present conditions but nevertheless noted for very high birth rates. There is also a need for more reliable and accurate information as to the location of known and potential food supplies, the greater utilization of hitherto untapped or inadequately used food supply sources, better distribution of food to avoid waste and spoilage, improvement of food and fiber producing techniques, and the extension of areas engaged in food and fiber production. A world-wide survey of all aspects of agricultural applications, including an inventory of resources available and an analysis of potential for food and fiber growth for all areas would be a primary requirement.

Shifts of population from rural to urban areas in recent years has created problems for both types of communities. Otherwise good farm land is often sacrificed to make way for suburban housing developments and the demand for rapid transit systems and other public services in metropolitan areas has often conflicted with the need for property tax revenues of city governments. There is need for planning for better economic uses of land in these areas, provision for zoning, evaluation of alternative locations for key facilities and for direction of growth. There is also need for a study of the problems caused by rising city taxes, urban congestion, inadequate expenditures for schools, recreation, fire and police protection, pollution control, and the reluctance of new industries to locate in large cities plagued by disorder and violence.

The tendency of some rural areas to deteriorate and for rural population to stagnate needs further study to see what might be done to improve the situation. Opportunities for further decentralization of industry and the planning of new recreational activities for such areas should be explored. While we are particularly concerned with trying to solve the problems that beset our own urban and rural communities, a global survey of such matters could be mutually advantageous to this nation and others.

The importance of education to man's survival cannot be overemphasized. Unless the majority of the people can be sufficiently informed about and made to understand the significance of the problems mentioned in this report and unless rational public reaction and cooperation can be stimulated to demand that more be done than has been done so far to cope with these problems because of the conviction that they and their future are directly involved, the problems will not only remain but will also proliferate. To be educated should mean more than to be informed. It should mean also being willing and able to do whatever is necessary to put that information to work for worthy purposes. The wise use of earth resources must be one of the primary goals of education.

Survival also depends on the degree to which individuals and nations can manage to settle their differences by amicable means rather than by force of arms and to accept the rule of law as a prerequisite to an orderly society. Political and legal problems are not always easy to negotiate but the need of reaching consensus on basic principles of conduct and finding ways of assuring cooperation in the application and implementation of those principles becomes increasingly important as the nations of the world become more and more interdependent and problems that were once local become global in their implications. Man's exploration of space raises many new problems of jurisdiction, responsibility, and liability that need to be resolved if the new frontiers being created are to be frontiers of peace and not new perimeters of hate and hostility.

The heavy burden of military expenditures on the taxpayer, the drainage of needed manpower and resources from the country, and the resulting postponement and neglect of many important domestic and other non-military needs raises the question of whether the $80 billion or more spent annually by the United States on defense is the wisest allocation of our resources or the best way to defend this country's interest. If we continue to prepare for war because we believe war is inevitable, it probably will be. Perhaps serious consideration should be given to rejecting this assumption.

Another problem that has not yet been resolved satisfactorily is that of ethnic and minority group relationships. While considerable progress has been made here and elsewhere, much more needs to be done to bring about the goal of equal treatment for all, regardless of color, creed, or ethnic background.

Nor is the above list complete by any means. Many more problems and needs could be added but these are at least representative of some that have been most pressing and persistent in recent years. They are stated in very general terms with no attempt to rank them in order of importance. The purpose here is not to evaluate the feasibility of various alternative solutions but merely to stress the fact that a real need for solution of all these problems does exist and to recommend that more effective action be taken than has heretofore been the case in trying to bring this about.

Specific problems and needs peculiar to special disciplines are also significant and, although it would be rather fruitless to attempt to catalogue them all, a few samples indicate the nature of some of these. In many instances they tend to parallel some of the broader socio-economic issues already discussed, but attention is focused more on earth resources and disciplines generally associated with them.

Thus, **Geography** is the science that describes the surface of the earth and its associated physical, biological, economic, political, and demographic characteristics, especially in terms of large areas and the complex of interrelationships among them. **Geodesy** is the science dealing with the determination of the shape, size, area, and curvature of the earth, with the precise mapping of continents or other large tracts, or location of specific points. **Cartography** refers to the art of drawing or compiling maps or charts. **Geology** is the science that deals with the origin and structure of the earth, including the physical forces which have shaped it and its physical and organic history, especially as evidenced by rocks and rock formations. **Hydrology** is that branch of physical geography that deals with the waters of the earth, their distribution, characteristics, and relation to human activities. **Oceanography** is that branch of physical geography pertaining to oceanic life and phenomena. Finally, **Agriculture** is the science that deals with the cultivation of the soil, the raising of food crops, breeding and raising of livestock, etc. and **Forestry** is the science concerned with the planting and managing of forests.

Resources related to these various disciplines might be roughly divided into those associated with water and those associated with land, although the division is not absolute. On a global basis, probably the most pressing need for all of these disciplines is to obtain sufficient data that will provide a reasonably accurate and current inventory of resources useful to man, with the expectation that this information will then be put to use.

Cartographers, geographers, and geodesists are all interested in improving the various types of measurements they make of the earth's physical features, including biological, geological, and cultural. Much of the data needed can be obtained by measuring the electromagnetic spectral or band reflectance or emission of energy. Synoptic views of the earth obtained from earth orbital heights are especially needed in order to construct up-to-date maps of large areas which are useful for predicting resource usage, distribution patterns, trends and inventories. Distortion due to the earth's curvature is minimal at that altitude and frequent observations can detect changes taking place which would not appear on conventional maps.

Geologic resources are capable of being used for the satisfaction of a wide variety of human wants. These include oil, gas, coal, nuclear and geothermal materials used for fuel and energy, numerous types of precious and semi-precious stones and minerals, various kinds of materials important to industry and construction such as metals, chemicals, stone, clay, sand and gravel. Improved methods of location, inventory, and use management of these resources, many of which are in critically short supply, would be welcome, as would greater understanding of the nature and causes of geologic processes generally.

More information is also needed about the distribution of water (ice, snow, rivers, lakes, estuaries, atmospheric moisture, groundwater, salt water, etc.), water dynamics (surface flow, evaporation, transpiration, etc.), and the quality of water (dissolved load, suspended load, thermal pollution, etc.). Greater use of biological resources in the ocean and perhaps improved use management of them as well might result if better information could be obtained about their location and distribution patterns, quantity, quality, and types. Greater knowledge of coastal marine processes and of ocean currents is needed and so are better quality ocean maps. In the field of navigation, there is need of more accurate and up-to-date information about the location of ships and hazards to shipping, of prompter and more accurate methods of reporting ships in distress and disasters at sea so that rescue operations can be more successful, and of better advance information that can assist navigators in planning safer or more economical routing of ships.

Land resources may be used for many purposes: residence, manufacturing, transportation, communication, utilities, trade, culture, entertainment, recreation, resource production and extraction among others. In addition, there is always some undeveloped land with numerous potential uses. A global data gathering program could be of value in providing the type of relevant information needed if the effectiveness of planning and regulating land use is to be improved. Even with complete information on the location, quality and quantity of all earth resources and global distribution of such information, there is no guarantee that these resources actually would be utilized more effectively and more fairly but the opportunity for doing so, at least, could no longer be traced to the insufficiency of pertinent data.

The uneven distribution of the world's food supply is already well documented, although not enough has been done to remedy the situation. It is hoped that an earth resources survey system might be used to inventory, predict, and to increase the potential for world food supply and also aid in improving its distribution. More specifically, greater attention could be given to such factors as land planning and management, animal inventory and grazing inventories, soil analyses, crop census, foliage density, dominant species, plant vigor, stress detection, and water resources inventories and analyses.

Better forest surveys are also needed to determine area patterns, state of advancement of forest growth, predicting harvest time, detecting and assessing disease, insect infestation, drought, flood, fire, and windstorm damage, suggesting proper cutting and logging operations, and for planning re-planting projects. More speed and accuracy in the detection and reporting of forest fires would also be possible.

It would be difficult, perhaps, to single out any of the physical or social sciences which could not, directly or indirectly, benefit from the consequences of establishing an operational earth resources survey system. Better detection and identification of archeological sites and distinguishing stone alignments or remains of extinct canal systems could be beneficial to a number of disciplines. The use of remote sensors for detecting structural faults, unusual concentrations of soil and water temperature, and underground mine fires clearly has demonstrated their value in forewarning of earthquakes, volcanic eruptions, and mine cave-ins. Many disciplines can profit from this type of information. The future determination of residential, factory, and recreational area sites, highway routing, hydro-electric and flood control projects, and various conservation activities will rely to an increasing degree on the kind of information only obtainable from great heights above the earth where the problem can be seen in terms of global reference.

It certainly should not be implied that instant Utopia or panaceas for all of the world's problems would come about through the adoption of any comprehensive earth resources survey system and the initial costs of such a system should not be minimized. On the other hand, there is probably greater danger of grossly underestimating all of the potential benefits of an operational system than there is of over-exaggerating them, since the possibilities are limited only by man's imagination and will. If, for the moment, no sense of urgency seems evident, it may be that not enough people have been made aware of the reality of that urgency or how it affects their daily lives and those of their progeny.

The disadvantages of trying to meet each need separately isolated from other needs are obvious. The need for new sources of energy posed by the increasing depletion of conventional sources can be partially resolved by rapid expansion of the use of nuclear power. However, the cost of providing adequate safeguards for society may prove so great that we sacrifice two other important needs, the need of protection from slow but lethal doses of radiation pollution and the need of security from disasters caused by nuclear explosion. To satisfy the world's need for food we can increase the supply but if we continue to lower the death rate but not the birth rate we will still be increasing the likelihood of other types of disasters caused by the population explosion.

One conclusion that emerges from these considerations is that all of these needs are interdependent in one way or another, so that an advance, a set-back, or continued neglect in meeting any one of them may at the same time affect progress in meeting one or more of the others. A corollary of this conclusion is that they not only are closely associated in their effects on one another but they are likewise global in their incidence and therefore of concern to all mankind.

It follows therefore that the best approach to their management should be one that treats them all as components of a single universal need—the need for survival—a problem which should invoke the cooperation of all peoples everywhere in trying to deal with it. The odds are even now too formidable for many segments of the world's population to help themselves. It would be to our advantage as well as theirs if means can be devised to improve their ability to deal with their own problems.

2.3 NECESSITY FOR AN INTERDISCIPLINARY APPROACH The reader has perhaps observed certain relationships between the problems and disciplines discussed previously. The problems are in fact interrelated, as are the disciplines. In addition, several of the disciplines are pertinent to each of the problems. The connections between the various problems and disciplines are so complex that no single, all-inclusive exposition of the interrelations is possible. However, some examples of the interdependence of the problems and disciplines will serve to illustrate the need for a uniform interdisciplinary approach to the management of earth resources. The problem areas of hunger and energy will be used for this purpose.

Relationships Between Problems

Consider first hunger, an increasingly critical problem in the underdeveloped nations of the world. One approach to the hunger problem is to increase the world supply of food by placing more land under cultivation and by increasing the yield of farmlands. The conversion of wilderness and nonarable areas to agricultural production introduces the need for wildlife management and consideration of associated conservation problems. The use of pesticides to increase crop yields immediately involves the problem of pollution. The problem of detection of disasters such as fire, floods and drought is also of prime importance in increasing crop yields.

In addition, the transportation of fertilizers to farmlands and the transportation of harvested crops to the population centers where they will be consumed must be considered as a part of the solution to the problem of world hunger; therefore, the problems of population density and transportation are related to the hunger problem. Finally, and perhaps most importantly, it must be realized that the solution to the problems of hunger in the world lies in the education of the citizens of the world, especially those of the underdeveloped nations, and in increased trust and understanding between the nations of the world. Thus, with the inclusion of the educational and the legal and political problems, the circle of interrelationships between hunger and the other problems is complete.

One of the dominant characteristics of the developed nations of the world is the production of vast quantities of energy in the form of heat, electricity and mechanical motion. In relating energy to other problem areas it is obvious that energy is vital to food production, transportation, education, industry, the military establishment–indeed to every facet of life in a developed society. Furthermore, the energy requirements depend on population densities and form a part of the knowledge required for regional and urban planning. Unfortunately, the production of energy from fuels results in pollution caused by the combustion of hydrocarbons, pollution of water by effluents from petroleum production and refining facilities or thermal pollution of water by nuclear power plants; these by-products of energy production must be considered in both present and future planning of energy supplies.

Conservation, not only of energy resources, but of wildlife, vegetation, water, and other resources vital to the ecological balance are intimately related to pollution and therefore to the production of energy. The legal and political problems involved in the control of pollution seem more difficult to solve than the economic and technical problems. Solutions to the legal and political problems, if such solutions are possible, will result from educational programs aimed at acquainting the populace with pollution problems, thus generating support for the legislation and subsequent enforcement necessary to control pollution. Public opinion will also have a direct effect on many polluting industries, thus reducing the need for government regulation.

Relationships Between Problems and Disciplines

As an example of the relation between problems and disciplines consider the several disciplines concerned with the problem of hunger. The discipline of agriculture is obviously related as is oceanography through the fisheries industry. Hydrology must be included since water supplies are vital to the production of both food crops and livestock.

Since the decision to grow food crops on a particular land area implies a decision not to place the land in timber production or use it for industrial and urban needs, forestry along with land use and urban development are added to the list of related disciplines. In addition, the disciplines of geography and cartography are involved in planning land use for food production pruposes.

Other Relationships

The previous examples illustrate that problem areas are neither independent of other problem areas nor of the disciplines. Similar relations may be found among the disciplines. For example, cartography is an integral part of the other disciplines that have been considered. It is not necessary to cite further examples to demonstrate the interdependence and overlap among the disciplines. There are, however, other relationships between the problems and disciplines in addition to those discussed above. Some bonds exist due to the fact that the sensors used to measure parameters pertinent to earth resources will be common to several disciplines and therefore to several problem areas.

Conclusion

The deep and complex linkages between the problems and disciplines related to earth resources lead to the ineluctable conclusion that significant progress in the management of earth resources can be achieved only with a uniform, interdisciplinary approach. Indeed, the planet earth must be treated as a system whose operation is to be optimized in such a way as to continuously provide the best possible quality of life for all its inhabitants. Although it can be validly argued that man with his finite wisdom and other human shortcomings cannot even define the "best possible quality of life" much less implement the changes that will produce the optimum earth system, such a systems approach can avert potential disasters lethal to the human race and perhaps produce changes that are generally accepted as improvements. Any other approach to the problem will have a drastically smaller probability of achieving even limited goals.

A systems approach implies not only the identification of problems, assignment of values and priorities, collection of data, and formulation of plans for improvement, but the education and the development of international trust and cooperation necessary to implement the plans. The earth resources system design set forth subsequently attempts to fulfill as many of these objectives as possible.

CHAPTER III

FEASIBILITY STUDY

3.1 **SPECIFIC DATA NEEDS** The study of data needs and users have been divided into two phases. Phase I covers the feasibility stage being discussed in this section. The primary objective here is to identify, in a preliminary fashion, those data needs or applications that might be satisfied by an earth resources survey system; more precisely:

(1) Specification of the kind of data required
(2) Specification of resolution and accuracy required
(3) Specification of frequency of coverage required

In Phase I a substantial body of information dealing with potential earth resources survey applications is available from several sources. In addition to the research done by the entire systems design team at the beginning of this project (see Needs Analysis Supplement), this study draws on much of the literature dealing with potential applications as well as material presented by visiting lecturers and consultants. These sources provide the pool of potential applications from which the preliminary candidates for inclusion in an operational survey system can be selected on the basis of the criteria and assumptions discussed below.

First, potential applications must appear to be amenable to an earth resources survey system. If there does not appear to be any way that remote sensing could reasonably be expected to contribute information useful in solving some problem or satisfying some need, that application is excluded from further consideration.

Despite the requirement that all candidates must appear amenable to an earth resources survey system, candidates are not included or excluded on the basis of how suitable they are in terms of existing sensor technology. In effect it is assumed that a sensor could be developed to obtain the necessary data.

Third, since there is presently an active satellite-based meteorological data gathering system, it is assumed that there would be no meteorology applications in the operational system.

Fourth, an application must appear to yield economic benefits or significant social benefits (e.g., lives might be saved) or, if the application is of a pure-research nature, the research must be of a critical kind (i.e., having a direct relationship to some pressing national or global problem).

Table 3.1 contains a listing of those applications that meet the criteria and comply with the assumptions discussed above.

It is important to recognize that the applications listed in the table remain highly tentative and serve largely as a preliminary basis for the definition of data acquisition plat forms, as well as data handling and administrative functions, as well as to narrow the field of candidates to be studied in the second phase of the analysis.

To attempt to identify with any degree of confidence those applications that qualify for inclusion in an operational system, a second phase in the screening procedure is required. Although a detailed discussion of Phase II results appears in Section 4.1, it is useful here to sketch out the nature of the analysis and to offer some preliminary observations about the conclusions. In Phase II an attempt is made to answer each of the following questions, where relevant, with respect to each of the candidate applications listed above:

TABLE 3.1

Prime Candidates (Unranked) for Earth Resources Survey System

Agriculture
- Crop Inventory and Forecast
- Crop Stress Detection
- Water Loss Along Irrigation Canals

Disaster
- Forest Fires Monitoring
- Search and Rescue
- Snow and Glacier Monitoring
- Volcano and Fault Monitoring
- Mine Fires

Forestry
- Mineral Identification
- Silting and Erosion Detection

Health
- Air and Water Pollution Detection
- Disease Detection

Mapping

Oceanography
- Fish Location and Identification
- Iceberg Location
- Sea State
- Fresh Water-Salt Water Interface

Resource Management-Conservation
- Wildlife Migration
- Underground Water Detection
- Drainage Basin Characteristics
- Thermal Detection - Geysers
- Power Dam Management
- Grazing Land Management

A. Are more or better quality data needed?

B. Why are the data needed?

1. Clear economic benefits?
2. Losses to anyone?
3. Savings of human lives?

4. Data needed in order to further critical research activity?
5. Apparent important contributions to knowledge about preserving ecological balance?
6. Probable payoffs in terms of promoting "peaceful and good" interpersonal, national, and international relations?

C. What kind of data are needed?

D. Who are the users?

E. How will the data be used to contribute to problem solving?

F. How much is currently spent to acquire this data?

G. What are the net economic benefits from collecting the data via the earth resource survey system?

It must be emphasized that time and manpower constraints has limited the Phase II effort largely to a survey on evaluation of the major case studies of proposed applications that have been prepared in recent years. Where more information has been required to complete the assessment of a given application, additional source material and technical consultation have been utilized. Although the Phase II results are definitely provisional, it is believed that the conclusions reached will contribute materially to future planning of the operational system.

3.2 REMOTE SENSING TECHNIQUES

Introduction

Except for gravimeters and magnetometers, most remote sensor instrumentation involves measurement in the electromagnetic spectrum. These measurements involve spectral or band absorptance of incoming energy which is the sum of the reflected and emitted energy from objects on the earth's surface. If the instrument draws power to emit a signal whose return is monitored, then it is an active system. Likewise, if power is drawn only in measuring the incoming energy, then the system is passive. Thus the major task of remote sensing is to obtain sufficient information in different spectral regions so that a unique signature can be assigned to each object of interest. It is in this area that much research is needed to determine which spectral bands are required for these unique signatures. It should be kept in mind that in many applications the information desired can only be inferred from the measured parameter. In other instances a set of data contains sufficient information such that numerous needs can be satisfied. In this respect the ultimate use of the data will often be unknown at the time of its acquisition.

Design Considerations

The design of a remote sensing system requires the selection of sensors and platforms which will satisfy a given set of data requirements. The platforms available consist of satellites, aircraft and in-situ ground sensors. A measurement system can consist of any one or a combination of these platforms. Thus, the first phase of a feasibility study must involve an investigation of the characteristics of each sensor and their compatability with one another when mounted on the same platform as well as their integration when mounted on separate platforms. To evaluate individual sensors, it is necessary to consider such characteristics as the operating spectral range, weight, power requirements, dimensions, resolution and data format and rate, to name a few. When considering a group of different sensors on a single platform, it is necessary to investigate power, weight, pointing accuracy and platform stability constraints in light of sensor requirements. In addition, deployable structures and antennas required for telemetry, tracking and control must be analyzed in certain instances.

The sensors considered for remote sensing application are return beam vidicons, image orthicons, metric and panoramic cameras, multichannel scanners, radar imagers, radar scatterometers, microwave imagers, microwave scatterometers, interferometers, spectrophotometers, magnetometers, gravimeters, radar altimeters, laser altimeters, radio frequency reflectometers, and a wide variety of in situ earth, buoy and balloon based sensors. A listing of some of the sensors and their characteristics can be found in Table 3.2. A description of many of these instruments is contained in the Glossary of Scientific Terms and Techniques.

The ultimate goal of this phase of the study is to determine the state of the art and future capability of each sensor. In assessing future capability it is assumed that the technological feasibility of a sensor would be based entirely on technological considerations with no consideration being given to time, manpower for development or cost. It is felt that the operational needs of the system would dictate the time scale and expenditure bounds for implementation.

As a result of this evaluation certain facts become evident. The problems most pressing in remote sensing are not technological in nature. The ability to acquire large amounts of qualitative data is well within technological limits. The major problem will be training people in the interpretation and application of this data. Without proper implementation of this task, none of the predicted grandiose benefits will ever be attained. Due to the large expenditure in hardware for an operational system, much effort and planning should precede the actual system implementation to insure a reasonable economic return from the investment.

TABLE 3.2

Remote Sensors and their Characteristics

Instrument	Operation Spectral Band in microns (GHZ)	Time of use Day/Night	Swath width in statute miles or (FOV)
1. Return beam vidicon	-4 - .81	X/	100
2. Image orthicon camera.	.8 - 1.0	X/X	100
3. Multispectral scanner	.3 - 14	X/X	100
4. Wide range image spectrophotometer	.45 - .80	X/	100
5. Radar scatterometer	(13.3)	X/X	(120)
6. Microwave radiometer	(19.35)	X/X	(100)
7. Microwave radiometer/ scatterometer	(10)	X/X	600 (72)
8. Data collection system	(.4 x mit) (.46 Recv)	X/X	NA
9. Metric cameras	.3 - 1.0	X/	100
10. High resolution panoramic camera	.3 - 1.0	X/	100
11. Ultra high resol. camera with telescope	.3 - 1.0	X/	30
12. Radar altimeter	(8)	X/X	[40]
13. Laser altimeter	0.6943	X/	(10 sec) [.20]
14. Syncotic multi band camera	.35 - 1.0	X/	100

Ground Resolution from 500nm FT (SM), [MR]	Data Base Bandwidth HZ/Chan. (bits/sec)	Weight Lbs.	Volume In^3 $[Ft^3]$	Power in watts
250 - 400	2.5×10^6	100	1170	55
500	60×10^3	42	1300	60
100 - 600	.15 to $1.0 \mathrm{x} 0^6$	140	700	55-110
200	$.7 \times 10^6$	20		8
3.5°	1×10^3	45		40
2.85° x 2.85°	100	50	600	25
2° x 2° (20)	1×10^3	52	600	27
NA	12.5 kb/sec	29		108 PK 128 SB
100	16 lb/day	500	[50]	50
30	1 lb/1000nm track	700	[75]	100
15	2 lb/orbit	900	[75]	900
1 - 2 vert.	5×10^8 bits/orbit 20×10^6 (4000)	50	[18]	220
1 - 2 vert.	50×10^6	75	[2.6]	75
100 - 200	1.5 lb/orbit	200	[50]	50

TABLE 3.2 (cont'd)

Instrument	Operation Spectral Band in microns (GHZ)	Time of use Day/Night	Swath width in statute miles or (FOV)
15. Radar imager	(8)	X/X	
16. Infrared radiometer	8 - 13	X/X	(120)
17. Ultraviolet imager/spectrometer	.3 - .5	X/	(1°)
18. Radio frequency reflectometer	(75 - 450 MHZ/SEC)	X/X	
19. Magnetometer	(0.2 - 0.5 Gauss)	X/X	
20. Gravimeter or gravity gradient	<1 g's or .005 Eotvos Units	X/X	
21. Temperature humidity IR radiometer	6.5 - 7.0 10.5 - 12.5	X/X	100
22. Interferometer	2.30 - 2.40	X/	{500 600

Ground Resolution from 500nm FT (SM, [MR]	Data Base Bandwidth HZ/Chan. (bits/sec)	Weight Lbs.	Volume Lbs. [Ft^3]	Power in watts
50 x 50	5 lb film/orbit	210 with recorder	[13]	550
1500	100 x 10^3	60	[3.9]	55
200	(1500)	80	[2]	40
(100)	(3 x 10^3)	40	[2]	40
(5)	10^6 bits/day	50	[5] +boom	50
5 x 10^{-12} gals/cm		20	[4]	20
(12) 21 (4) 7	115 345	17	400	7
(20) 2°	(100)	50	2600	25

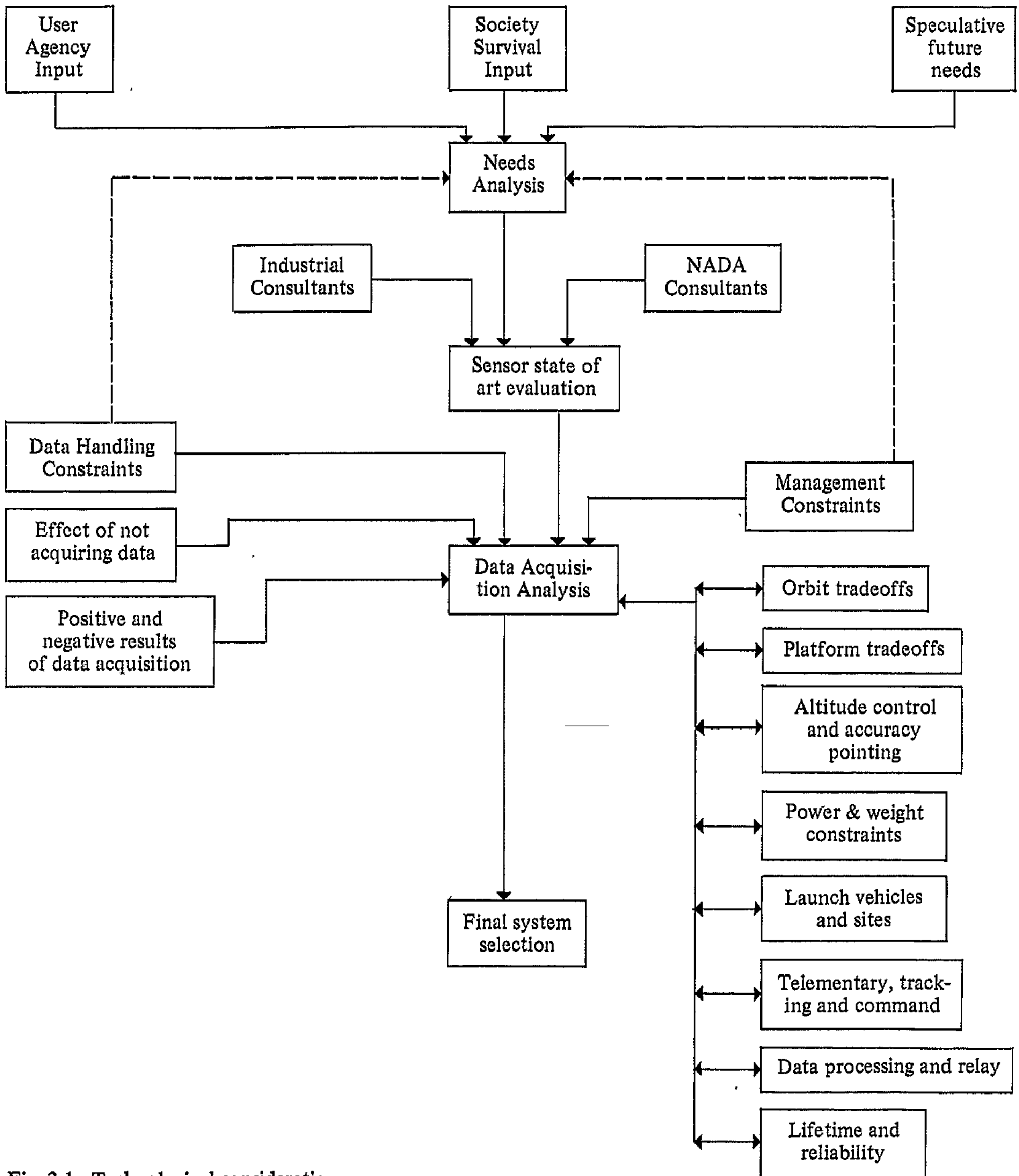


Fig. 3.1. Technological considerations for data acquisition

3.3 CONSIDERATIONS FOR AN OPERATIONAL SYSTEM

Data Acquisition

The major consideration of data acquisition is to determine the feasibility of obtaining the necessary earth resources information with various sensors mounted on satellites, aircraft and ground based platforms. A block diagram of the logic used in this analysis is contained in Fig. 3.1.

The initial sensor evaluation has been conducted using inputs from both in-house NASA consultants and industrial consultants. A review of this phase of the study is contained in the previous section entitled Remote Sensing Techniques. The determining factors which limit the feasibility of any sensor to any platform are power, weight, data format and rate, deployable structures, and pointing accuracy requirements. Some general guidelines have been developed concerning which platforms are best qualified to contain certain sensors.

The first is the possibility of relegating the use of photography to aircraft. It is felt that the major contribution that a satellite might make is to obtain global mapping of gross features at repeated intervals of time. In the advent of local change in a desired parameter, the aircraft could be used for accurate interrogation of the area in question. Photographic techniques yield high information density, high resolution and metric accuracy, but are limited by cloud cover and darkness, require film recovery, require excessive weight and volume for long duration missions, and do not present a data format readily adaptable to electronic data handling. In addition, return beam vidicons and multichannel scanners provide information in the same region of the spectrum as photography, with lower resolution, but in a form amenable to spectral signature analysis and transmission. Secondly, side looking radar might be relegated to the aircraft platform. The major reason for this is due to power, weight, and resolution requirements. It is possible, with future development, that a satellite version could be available, but it appears that a radar scatterometer/radiometer could provide the needed all weather capability. Radar altimetry systems appear to be superior to laser systems for a number of reasons regardless of whether the platform is an aircraft or a satellite. First, the radar is an all weather system, whereas the laser is strongly influenced by cloud cover and atmospheric attenuation. The laser system requires a knowledge of altitude to within 10 arc seconds, while the radar system does not require any altitude information over the same range of altitude angle. The radar system footprint is about 2500 times the area of the laser, resulting in better spatial averaging. The radar averages about 10^5 pulses per second to provide a time average, while the laser system observes one pulse per datum point. The major disadvantages of the radar system is that it yields ten times the data rate of the laser system.

It is also possible that an operational system should contain an information retrieval system for interrogation of ground based sensors. Such a system should include navigation, meteorological and tracking control if at all possible.

In addition, the use of relay satellites is considered to be feasible. A system of a minimum of three, but preferably more, geosynchronous relay satellites has multiple uses, only one of which is the acquisition of earth resources data. A number of technological problems are yet to be solved before such a system can be operational but they are within the reach of technology. ATS-F and Nimbus E will be flown in the near future to demonstrate the tracking and communication limits between a geosynchronous and polar orbiting satellite. Presently X and S band communications links are being considered and if larger bandwidths prove necessary, research will be required to develop millimeter band hardware (in particular modulators and demodulators).

The relay system has many advantages over additional ground stations. It provides centralized control and processing from one or at most two ground stations. In addition, it provides real time coverage of 90% of the globe. The system becomes independent of political pressures and interference in operation. However, frequency allocation does become important and must be overcome before such a system can become operational. With the predicted lifetime of 5 to 10 years, this system can be cost competitive with ground station implementation and operational costs. If a ground network replaced a relay network, loss of a ground station or two in an operational system, regardless of the cause, would render the system useless. This is also true if a relay satellite were lost, but back-up satellites could be launched. If a country impounds a ground station within its borders, there is not too much that can be done to replace the loss to the system.

In considering an operational system the major goal is to place the necessary sensors on the optimum platform for attainment of the specific data needs. In order to accomplish this task the specific data needs must be well defined. The initial phase of the study has been concerned with identifying the specific user and societal needs. The real probelm arises when an attempt is made to decide upon a priority system for evaluation of these needs. Much speculation has gone into numerous cost/benefit studies. However, the results have been vague and confusing and can only yield marginal information for a needs analysis. The questions to be raised concern the need for the acquisition of more data. How much existing data is available and of what quality? How would the acquisition of more data be integrated with existing data? Would the present social and political structure prevent effective or meaningful use of the data? For a more detailed description of the criteria the reader is referred to Chapter II and Section 4.1.

It thus appears that the acquisition of the data required for an operational earth resources survey is well within technological limits. Due to the complexity and multiple technological facets of the analysis, many of the conclusions reached in the preliminary design are based upon information obtained from the technical literature and communication with available consultants. As such, the conclusions reached are only as good as the sources of information and the ability of the team to synthesize the available facts in the time allotted for analysis. The major problem this system is to face is not its ability to collect data. The problems of data handling and ability to utilize the data at the rate at which it is collected will tax our technological expertise.

Data Handling

Introduction In approaching the data handling problem, three task areas have been delineated. The interaction envisioned between these tasks and the control feedback, as a possible arrangement, is illustrated in the block diagram of Fig. 3.2. For purposes of study and evaluation, each of these tasks can be divided into subsystems with a view toward proper integration so that ultimately the total data handling system will evolve into a compatible, efficient user-oriented system.

For purposes of discussion the data may be considered to flow from the collection sites to the processing and storage areas and on to the distribution point. The feedback control is arranged so that an input request is transmitted from the user to the distribution center. The distribution center would in turn transmit the user data requirements to the processing area. The function of the processing area would be to process the data according to user requirements. In cases where new or different types of data are needed, the distribution center would initiate the collection of the requested data. It is recognized that for an operational system, it is of utmost importance that the data handling system be user oriented.

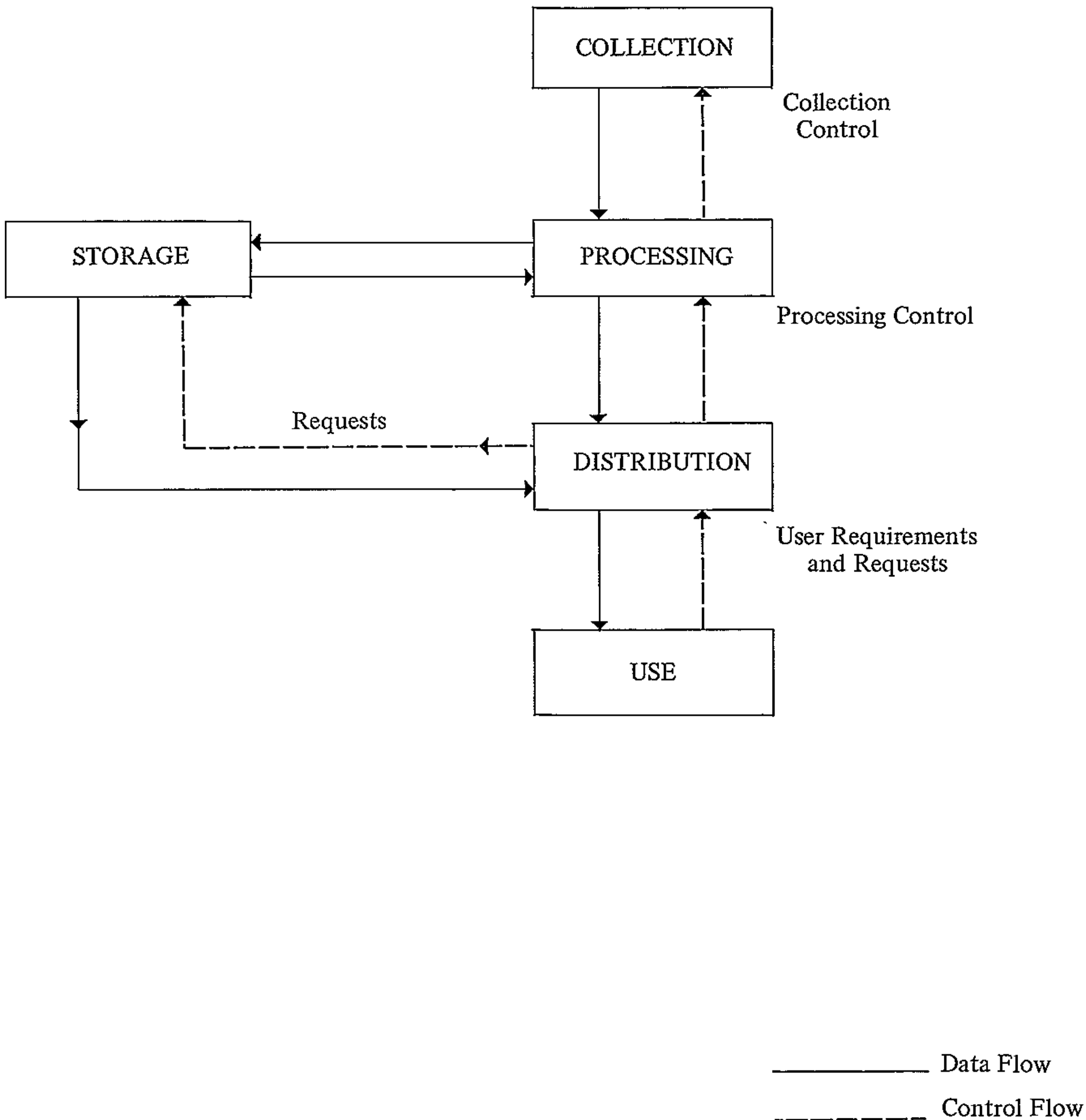


Fig. 3.2 Information flow diagram for data handling system

Objectives of the Data Handling System The primary goal of the data handling system is to assist users in defining and fulfilling their information needs. Users and potential users (hereafter, in enumerating and discussing the objectives, the term user will generally encompass both actual and potential users) should have knowledge of (1) what data are available, (2) what services are provided, and (3) how to obtain the data and utilize the services provided by the system. Specific objectives to guide the system in attaining the primary goal, along with some measures of performance, are discussed in the following paragraphs.

Users should receive information about what data and services are available. Descriptive literature should be prepared and sent to major users periodically and to any interested party upon request. Informational conferences and training sessions should be conducted periodically on a geographical and/or user type basis; some of these activities may be performed by other governmental agencies, educational institutions, and commercial organizations. A measure of performance can be based upon the extent to which users are knowledgeable about the data and services available; the necessary information could be obtained for example by an annual survey of users.

Additionally, the data handling system should process user requests in a timely and economical manner. Requests for data to be acquired in the future would be collected and sent to an administrative control center. Users requesting data not in the system may be referred to some other organization. One measure of performance, with respect to data supplied by the system, might be the percentage of requests fulfilled within an appropriate time interval; the length of the interval should vary with the urgency of the need for the data and the amount of processing required. A measure of whether or not requests are processed in an economical manner could include a consideration of the amount of over- or under-utilization of system facilities and personnel as well as cost per image or data set.

Data would be sent to a data handling center within X days of observation X varying with the sensor platform or observation method and the frequency of collection for transmittal to the center. Performance could then be measured by the percentage of the data received in usable condition at the center within X days.

Initial processing of data should be accomplished within a few hours of receipt. This would include development of film and analog-to-digital conversion, in addition to formatting, classifying, indexing, annotating, labeling and cataloging. Suitable measures of performance would include (1) number of errors per data set and (2) percent of data initially processed within a specified time period. The relative seriousness of the errors might also be considered in measure (1) above.

Pertinent data could be reviewed within a few hours of observation for phenomena requiring quick reaction. Two measures of performance seem appropriate: (1) percentage of pertinent data which goes through quick-look reviewing and (2) number and relative seriousness of errors in detection and interpretation.

Additional objectives pertain to storage of data. One of these objectives is to establish and maintain a permanent data bank. Data of less than a certain minimum quality might not be placed in the permanent data bank. Measures of performance could include (1) percentage of attempted retrievals that were successful, and (2) percentage of retrievals completed within X days, and (3) percentage degradation in quality per year. The other objective pertaining to storage of data could be to establish and maintain a working data bank. All original data and selected processed material could be stored therein. Periodically the working data bank would be purged of data for which there is no demand. Measures of performance would include (1) percentage of attempted retrievals that are successful, and (2) average time to retrieve data.

A data handling center should perform such processing as could be more economically done centrally than by users. A complicating aspect is that the actual performance of certain processing may have value to a user as a training device. A measure of performance for this objective can be the relative cost of processing by one versus several organizations.

Research in methods and systems of data acquisition, transmission, processing, analysis, and interpretation should be performed within the data handling system. Such research should be directed towards providing better service to users.

The final objective is that the system design should facilitate the orderly evolution of the data handling system. Some experience for an operational data handling system should be acquired through the ERTS series. The organization, policies, and facilities of the operational system should be sufficiently flexible to adapt to changes in user requirements, data sensors and/or platforms, and data handling hardware and software.

The non-specified times in the objectives and measures of performance should be established and continually updated by a mission-evaluation panel with representatives from operations, distribution, administration, users, etc. The times would be based primarily on the panel's appraisal of:

1. user requests
2. relative importance of user requirements
3. current system capacity and capability
4. feasibility of up-grading the system

Data Collection Information utilized in an earth resources survey program may be collected by an observational subsystem which could contain both space and ground components. The space components would include satellite-borne remote sensors and data relay facilities. The ground components would include sensors on aircraft, ships, and at *in situ* locations. Some of the data from ground components may be relayed to central collection points via satellite.

Operational control of data collection from satellites should be associated with the command and data acquisition stations. The necessary links between ground stations and orbiting satellites include: (1) wide-band links for on-board imagery sensors and (2) narrow-band links for data relay from ground-based sensors, command, and housekeeping, tracking and attitude control; and range and range rate. Administrative control should reside in the over-all system control unit.

Command and Ground Receiving Stations The number and location of ground stations should be chosen to provide communication between the satellites and the ground stations and between the ground stations and data handling facilities.

There are at least three system configurations that could provide global coverage from sun-synchronous satellites. One system would use a large number of ground stations distributed over the earth so that the sun-synchronous satellite is always within range of a ground station. This configuration would require an extensive ground data transmission network if a single data processing center is used, but would be well adapted to a system composed of a number of smaller processing centers located in the user countries.

A second system would use tape recorders on board the satellite to reduce the number of ground stations and consequently the complexity of the ground transmission network. There are serious doubts, however, concerning the possibility of developing an on-board tape recorder of reliability consistent with the expected lifetime of the other satellite components.

A third system would use a network of geosynchronous relay satellites to reduce the minimum number of ground stations to one, although a second ground station could be used to provide redundancy. Multiple ground stations might be an economically feasible alternate to ground data transmission links in a system utilizing multiple data handling centers. It should be noted that the use of geosynchronous relay satellites restricts the location of the ground stations to the lower latitudes.

On-Board Processing The quantity of data to be transmitted to the ground from an observation satellite with global coverage capability is a major problem that the system design must consider. One possible solution is to reduce the quantity of data transmitted by using highly selective acquisition. Only data that is actually requested by a user and that is above minimum quality would be taken. Another solution is to reduce the volume of data transmitted to the ground by performing some data processing to compress the data with an on-board computer. On-board processing could be used to make the decisions necessary for selective acquisition.

In the simplest form, the selective acquisition system would not use on-board processing but might use a low-resolution on-board television camera monitored on the ground by an operator who checks for cloud cover and controls the sensor operation. A more sophisticated system might utilize an on-board computer that detects cloud cover and initiates the proper sensor control signals. The ultimate on-board processing system might consist of a sophisticated signature recognition computer system having command control over the sensors so that data is transmitted to the ground only when the system identifies the features that it has been instructed to survey. This latter system, because it transmits only the refined data to the ground, has the capability of compressing the data.

There are a number of disadvantages to on-board processing. First, an on-board system is more expensive than an equivalent ground-based system. Second, the life of the computer is limited by the life of the satellite. Since there is no repair capability on the satellite, the actual computer lifetime may be less than the satellite lifetime. A third disadvantage concerns the present state of development of signature recognition techniques. While an on-board cloud recognition system is being developed at the present time, much signature recognition research will probably need to be done during the early states of the operational earth resources system. Signature recognition research will require transmission of sensor output to the ground, rather than the output of an on-board signature recognition system.

Data Processing Facilities The location and number of data processing centers is related to the number and location of ground stations, the amount of real-time processing to be done, and the location of the users.

Two problems associated with the location and number of data processing centers are the transmission of information between the ground stations and the centers, and the transmission of information between the centers and the users.

If the quantity of real-time data transmission between the ground stations and the data handling centers is small and limited to data requests, command and control data, and a small amount of imagery data for quick-look, then the cost of providing ground links will be small. On the other hand, if large quantities of imagery data must be processed in real time, then the cost of ground data links will be large, dictating that the data processing be done near the ground stations.

Because the system must be user-oriented to be of maximum benefit, a great deal of communication between the users and the data processing centers is necessary. This consideration suggests that the data processing centers be located as close as possible to the user agencies. In the beginning operational phases, the principle users will be the U. S. Department of Interior and the U. S. Department of Agriculture; therefore, a central data distribution point near Washington, D. C. seems advisable from the standpoint of user proximity. As the system develops and assumes global proportions, a single data processing center would necessitate a large distribution network.

A single processing center would obviously have economies of scale. A large number of processing centers located in the geographic vicinity of the users, while not providing economies of scale, would provide a highly user-oriented system together with a low cost network of communication between the processing center and the users.

Some countries might want their own data processing centers as an aid to their national technical development, as a means of avoiding suspicions resulting from unilateral control of the data, or simply as a matter of national pride. The concept of a number of processing centers in close proximity to the users would be quite compatible with a satellite to the ground data system employing a large number of ground stations. The multiple processing centers concept in combination with a single ground station would require a network for transmission between the ground station and the processing center. The network would be costly if a large amount of real-time processing were done.

A third system configuration might consist of a central processing center in which processing common to a large number of users is done, with the users performing processing unique to their needs at their own centers. This system affords both economies of scale and user involvement in critical areas of processing.

In summary, the selection of the number and location of data processing centers will involve trade-offs between optimum satellite-to-ground communications, optimum ground station-to-processing center communications, optimum processing center-to-user communications, and non-economic considerations, such as the likelihood of acceptance of the system by non-U. S. users and security problems in handling sensitive data.

Data Storage In making earth resources data available to users, two different philosophies of operation can be employed. One approach involves the acquisition and storage of as much data as possible, with no regard for whether or not there will ever be a use for the data. The alternate approach is that data will only be acquired and stored if there is a need for it. This latter approach implies that users initiate a request for specific data and also specify that the data not be acquired if there is so much cloud cover as to make the data useless. The first approach provides for the accumulation of data for uses not yet envisioned, but would require enormous storage and processing facilities to handle the data. The quantity of data processed and stored but never used would probably be greater than the quantity of data used subsequent to processing and storage.

If there is a limit to the funds and technology available for an earth resources survey system, then the philosophy of selective acquisition and storage of data will certainly provide more immediate benefits to society than the former philosophy. Successful implementation of the philosophy of selectivity will require a management or funding structure that provides some sort of control on data requests.

Administration

Alternatives Considered In planning for the administrative organization and management of an operational earth resources survey system, there are certain fundamental questions that must be answered before one can proceed. Should the system be private, public, or a combination of these similar to the Comsat arrangement? Should it be centered in the United Nations, should it include other national governments participating with the United States, or should it be limited to the United States government?

Should administration be centralized or decentralized? Should one try to make use of existing organizations as a foundation for the operational system or should a new one be created? Incorporation of some of the personnel, functions, or agencies presently engaged in preliminary experiments, research and development, data acquisition, processing, and distribution into a new administrative system also should be considered.

Where should responsibility be allocated for research and development, launching, command control, acquisition of data, analysis, processing, storage, and distribution of data, administrative policy-making liaison with domestic and foreign users of data, contractors and data acquisition agencies, the United Nations, Congress, learned societies and educational institutions, and the public? What arrangements should be made for clearance of data distributed to protect our national security and for the accessibility of data about one nation that might be requested by another nation? What other regulations or "ground rules" would be required? By whom should they be made?

Another important consideration is the determination of how the capital and operating costs of the system should be met. Is Congressional funding necessary? Should private and government agency users, domestic and foreign, pay part or all of the costs? Should any or all of the data acquired be available on a no-charge basis? How should costs be figured? How soon can the system be truly operational so that it pays for its own costs of operation?

If a national system is decided upon, how might such a system eventually serve as a bridge for the more distant prospect of an internationally administered earth resources survey system becoming operational? Finally, it is important that a system be designed that will promote full utilization of the data acquired, that will provide benefits for the greatest number possible, and that can be run efficiently and economically. How might this be done?

Criteria With the preceding questions in mind, certain criteria and measures of performance must be established. One of these criteria is **flexibility**. The organization must be capable of contraction as well as expansion and it must be adaptable to international participation as well as to changing technology. The organization must also be measured by its **responsiveness**, not only to individual and social user needs on a routine basis, but also in its ability to quickly react to an emergency. Another criterion is the **efficiency** of the organization, both within itself and in its relation to the entire parent structure of government. There should be minimal duplication of other agency activities, and a high degree of efficiency in data handling. Finally, the **security** aspects of the organization should dictate that no individual, group, or nation should have access to data about another nation without that nation's permission. The taking of data should not increase world tension; ways should be found to prevent any suspicion about the use or distribution of data.

Evaluation of Precedents While numerous studies are available on the problems involved in the acquisition and processing of data obtained from satellites, on the type of launching vehicles, sensors, and resolutions required, and even on the kinds of social, economic, and disciplinary needs that might be served by such a system, none is found which provides any plan for the administration of an operational system.

A careful look at the Comsat-Intelsat system for communication satellites shows the situation there to be rather unique. While it definitely is an operating system and does use satellites, it is not primarily engaged in acquiring, processing, storing or distributing data. Furthermore, the field of communications is one in which there already exists a long history of cooperation between nations, the International Telecommunications Union being the oldest existing international organization.

The Environmental Science Services Administration (ESSA) in the Department of Commerce also merits considerable attention, due to the fact that its purpose is "to describe, understand, and predict the state of the oceans, the state of the lower and upper atmosphere, and the size and shape of the earth, in order to further the safety and welfare of the public, enhance and improve the Nation's economy, and assist those Federal departments concerned with the national defense, the exploration of outer space, and the management of natural resources." [1] Its functions also include the conducting of ". . . comprehensive programs with respect to meteorology, climatology, hydrology, surveying, cartography, oceanography, terrestial and space investigations, electromagnetic wave propagation, electromagnetic properties of the atmosphere, telecommunications services . . ." [1]. In addition, ". . . research, observations, processing, dissemination of forecasts, warnings and information about the state of the oceans and inland waters, the upper and lower atmosphere, the space environment, and the earth" are listed. [1] The organization includes a National Natural Disaster Warning System (NADWARN), a National Environmental Satellite Center (NESC), an Environmental Data Service (EDS), space platforms including the TOS System of weather satellites: ESSA I and ESSA II, and Command and Acquisition stations at Gilmore Creek, Alaska and Wallops Island, Virginia. However, its location within a major governmental department, its primary concern with weather data, and the exclusion from its functions of certain features deemed essential to an operational earth resources survey system must also be considered.

Within the Department of Defense, earth resources data acquired is likely to be of rather high resolution but of too classified a nature generally for public distribution and decidedly not conducive to the securing of international cooperation if facilities within this department were to be part of any projected operational system. The Navy Oceanographic Office does a very comprehensive job of acquiring oceanographic data that could be useful in an earth resources survey program, but this represents a very small part of what would be needed.

Thus there appears to be little in the way of operating precedents that might serve as a possible model to follow in setting up an administrative system for earth resources surveying. Although suggestions have been made for establishing a new agency to take over the Weather Bureau, the Coast Guard, the Bureau of Commercial Fisheries and other activities as part of a national oceanic and atmospheric program, the problems inherent in such a proposal are formidable.

Evaluation of Alternatives If an ERTS satellite is successfully launched no later than 1972, 1975 seems appropriate as a target date for an operational system. Every effort should be made to secure the cooperation of other nations and to allay the fear of "spies in the sky." In order to achieve maximum utilization and benefits for the greatest number of data users and encourage international participation, it follows that the system should be global. At the same time, it would not be inconsistent with the global scope of the system if it was initially national in its administration with the intention that it would later be developed into an internationally administered system as soon as foreign interest and participation became sufficient to make this practical.

Under private management, the only direct costs to the public would be those of public regulation. It might be possible to become operational at an earlier date because funding would not have to wait for congressional appropriation and there could be less internal delay as well because of fewer management levels compared to a government-structured organization.

Disadvantages of a privately-managed system are numerous. The profit motive makes it necessary to recover costs by data sales to users able to pay. Mechanisms to prevent data leaking to nonpaying users would add to cost. Socially important data might not be processed and used because some users (e.g., smog control districts) might not be able to afford it. Large industries might have an unfair advantage over small ones. Non-participating countries might suspect a privately owned system of spying.

Virtually all space effort in the United States so far has been public, including research and development, launching, command control, ground stations, acquisition, processing, storage, distribution of data, financing, and administration. Much of this effort, in fact, has been initiated by the armed forces and there still exists a real need for safeguarding national security which necessitates some control over the acquisition and distribution of earth resources data by the State and Defense Departments. Furthermore, an operational earth resources survey system would likely require an administration that possesses the type of authority which only government is capable of exercising effectively in the area of rule making and rule enforcement.

If it is assumed that the system should be global in scope and that, eventually, it should be internationally administrated, a national government basis is more compatible with these assumptions than would be the case if the system were privately owned, operated, and administrated. While there might be greater delay in securing funds for the system, there might be more certainty of obtaining them to offset this. Perhaps governmental administration could assure greater protection to other governments against spying with greater possibility that the restrictions will be effectively enforced.

Although Comsat-Intelsat does demonstrate that a combined public-private system is possible for communications, a substantial number of countries believe that communications generally is too closely allied to considerations of national security to be entrusted to private enterprise entirely. It is even possible that the United States might eventually decide that domestic and international communication networks require greater direct governmental control as an alternative to present regulation of private companies.

With a system in which administration was centered in government, there would still remain almost unlimited opportunity for contracting with private firms for many phases of the system's operation. This has been the case during the preliminary stages of research and development and also in the operational stages of ESSA and other data acquiring agencies of government.

Organizational Structure The management structure of an earth resources survey system could be one of four basic types:

(1) management by a private enterprise

(2) management by a single national government

(3) management by a private international enterprise

(4) management by a public international organization

Many of the ideas expressed in the following discussion of these alternate forms of management are found in recent literature. [2]

Management by private enterprise would seem to have the advantage of limiting the direct public costs to the costs of public regulation since the system would operate using revenue from the sale of data. The public would, however, pay a large part of the cost of the system indirectly, since government agencies would, at least in the beginning, be principal data users. Many socially important data might not be obtained unless the costs were assumed by government agencies. The private enterprise system would likely be operational at an earlier date than a system which required Congressional appropriation or the approval of an international body. In addition, a private system with fewer management levels would implement management decisions with less delay than a government or international organization and would therefore be more efficient administratively.

A disadvantage of management by private enterprise is that the mechanism to prevent nonpaying users from obtaining data would add to the cost. Furthermore, small companies might not be able to pay for earth resources data and would be at a disadvantage with respect to large companies. Finally, a private enterprise confined to a single nation might be suspected of espionage.

Management by a single national government would eliminate the cost of a government regulatory agency paralleling the management structure of a private enterprise. In addition, the government structure would not be profit motivated and would be able to furnish data with social uses regardless of whether or not the data would lead to any immediate economic benefits.

Management by a single national government, which would require no formal multilateral agreements, would be much simpler than management by a public international organization.

This arrangement would also eliminate the inefficiencies resulting from a separation of the managerial and regulatory function inherent in management by a private enterprise. An earth resources survey system managed by a single national government would undoubtedly become a part of the nation's domestic and foreign policy. Certainly, protection of national security would be a factor in administrative decisions in such a system. If the nation chose to do so, data could be censored in the national interest. In an extreme case, the nation administering the earth resources data might conceivably control the data in such a way as to provide maximum benefits to itself at the expense of world-wide benefits. Even if such national bias were minimized or removed from the system entirely, the nation controlling the system would be subject to suspicion. A system with the capability of global coverage thus seems to be inherently suited to some sort of international management structure.

Management by a private international enterprise formed by private companies from different countries would avoid regulation by a single national interest. An international regulatory agency would be needed, however, and would introduce the additional cost of a regulatory structure paralleling the administrative structure. The establishment and operation of both the regulatory and management structure would be more difficult and time consuming than either of the national systems because of the international agreements that must be formed. A private international enterprise would nevertheless be more efficient administratively than a public international organization.

The private international enterprise would have more economic and technical resources available than would a private enterprise located in a single nation. As with the private enterprise located in a single nation, government agencies would have to provide funds for data of social and humanitarian benefit but lacking immediate economic benefits.

Administration by a public international organization would permit the utilization of economic and technical resources from a number of countries and at the same time promote technical and scientific advances within the member nations. The public administration concept would provide the best guarantee of maximum world-wide benefit of data collection and dissemination. An international organization of any type which involved different nations of the world in a common endeavor might promote better international understanding in other areas. Objections to international data acquisition through satellite overflights might be reduced as a result of better international understanding.

A distinct disadvantage of management by a public international organization is the long period of time required to form the organization. There is no existing public international organization that could assume the management of an earth resources survey; consequently, much time would need to be spent in negotiation between nations and in ratification by the participating countries before operations could begin. Many countries might not be willing or able to commit themselves to the earth resources program before the benefits of participation have been proven by an operational system. Finally, the decision-making procedures in a public international organization would be the most complex and time consuming of the four administrative structures considered.

The fact that each of the four administrative structures considered has both advantages and disadvantages leads to a consideration of the possibility that features from more than one of the management structures might be combined to produce a management structure that is superior to any of the component structures. The preliminary design concept detailed in Section 4.4 is such a combination.

Financing Several alternative arrangements for the financing of an earth resources survey system have been considered, ranging from sale of data to the highest bidder to the appropriation of all capital and operating funds for ERSA by Congress and the distribution of all data at no cost to all potential users. The first option could be rejected in part on the grounds that it would offer already powerful economic interests further opportunity to grow relative to the more diminutive firms and industries. Moreover, it would be extremely difficult to estimate beforehand what the value of much of the space or aircraft data would be to potential bidders and thus hard for them to resolve the price they should offer for this data. Also, difficult questions arise regarding the copyrighting privileges which the buyer would have or how quickly the data could be released for use by others when information is sold to the highest bidder. Since such data would probably have multiple uses, it would seem inefficient to restrict their use to one buyer for a lengthy period of time.

The second alternative might be rejected on the ground that it offered little test of the economic value of possible data which might be gathered by aircraft or satellite platforms. When data is made available free to all possible users, there develops a tendency to request all sorts of information regardless of its immediate or potential value. In such a case, users are not encouraged to consider the specific benefits from the data or to evaluate the cost of alternative methods of obtaining information of equivalent or better quality.

CHAPTER IV

PRELIMINARY DESIGN CONCEPT

This chapter discusses, on the basis of the considerations of Chapter III, a design concept for the TRIAD operational system. The data acquisition, data handling and administrative features of this system are predicated on the assumption that a meaningful analysis of specific data needs and priorities for an operational system can be performed. Thus Section 4.1, although certainly not challenging the need for earth resources data, does take issue with an unplanned indiscriminate collection of such data and seeks to provide a method for critically examining the need and relative importance of certain specific data. The suggested gross aspects of the data acquisition and data handling schemes are elucidated in Sections 4.2 and 4.3, respectively, while Section 4.4 details a plan for administration.

Although the preliminary design concept presented here represents the consensus of thinking of the summer study group, it is not purported to be the result of complete unanimity. Indeed, in view of the many elusive and often intangible aspects discussed here, it would be naive to expect that complete unanimity of thinking would ever result or even be desirable from any study. As an example, an alternative viewpoint on the justification for an earth resources survey system is presented in Appendix IV.

4.1 NEEDS AND NONSENSE There have been many studies, both broadly focused ones and those that explore specific applications in detail, of potential benefits to be obtained from an earth resources survey system. Much of this work represents an important contribution to the first stage of planning a survey system but, in many cases, it is weakened by apparent omissions that should be corrected in subsequent work. One of the omissions is the inadequate attention so far paid to how data obtained by a survey system will be utilized. Often this issue appears simply to have been ignored or assumed away in a manner that implies that if only the data are acquired they will be used to accomplish whatever objective they are intended to satisfy. On close scrutiny, however, considerations of how data can be used in problem solving or meeting objectives turn out to be among the weakest elements of the typical study of survey applications.

Less obvious, perhaps, at least to the layman are the technical inadequacies of much of the cost-benefit analysis of survey applications. Cost-benefit analysis can be a powerful tool to assist decision makers in choosing how to accomplish an objective in the least costly fashion, how to allocate a limited budget among competing projects, or in deciding whether a proposed project is even an economically defensible undertaking. But cost-benefit analysis has very clear limitations as a decision-making aid and, if they are not recognized, the quality of decision-making may deteriorate accordingly.

The purpose of this section is twofold. First, it offers some general observations regarding problems connected with data utilization and cost-benefit analysis, and it suggests some related work that needs doing as consideration of an operational survey system proceeds. Although the intent is not to be unduly harsh in judging work already done on these issues, the following comments are illustrated along the way by reference to some of the shortcomings of existing studies. Second, it furnishes a provisional assessment of the merits of various proposed survey applications based on an analysis of most of the major case studies prepared in recent years. The assessment is definitely not the last word regarding what ought to go aboard an operational survey system but, hopefully, it will be useful if only because it indicates the conclusions reached by one group of impartial observers.

The Problem of Data Utilization

The question of data utilization leads to consideration of the ultimate goal toward which the entire systems analysis and design effort described in this report is intended to contribute, namely, the making of decisions and the taking of action to achieve objectives in the area of earth resource. For unless the data to be acquired, analyzed, and disseminated are both necessary for and actually to be used in making decisions it is difficult to justify collecting them.[1] As one of the leading practitioners of systems analysis has observed: "What we seek to do in the systems analysis approach to problems is to examine an objective in its broadest sense, including its reasonableness or appropriateness from a national policy point of view, and then develop for the responsible decision maker information that will best help him to select the preferred way of achieving it." [1]

Examination of many of the studies of survey applications might lead one to conclude that the intent of some advocates is mainly to have an earth resources survey system regardless of whether it will aid in achieving some ultimate objective such as, say, improving agricultural production or eradicating some disease. Whether or not the inference is a correct one, the relative inattention in many studies to the problems of taking action on the basis of information acquired makes such a conclusion a fair one.

Undoubtedly some will argue that any apparent inattention to important issues is merely the result of doing first things first and will be corrected in subsequent work. Although data utilization issues are so crucial for an assessment of a proposed application that it seems unwise to delay dealing with them, this defense would be acceptable if the importance of the issues were recognized even implicitly. But it is the contention of this report that some of the studies advocating applications imply that the case has been made when it has simply been asserted that the data will be useful and more or less demonstrated that the data probably can be acquired.

For the most part, however, advocates of survey applications have advanced beyond the point of merely asserting utilization potential and likely acquisition. Now the prototype effort contains cost-benefit analysis of a sort to substantiate further the application in question. Unfortunately, inattention to critical issues of data utilization still abound in many of these otherwise more advanced efforts. These contentions can best be illustrated by reference to some studies involving proposed applications.

It has been suggested that a survey system can be used to inventory crops (from which forecasts of production can be prepared) and to detect crop stress more accurately, cheaply, or quickly than can present methods. Sometimes these applications are advocated on the premise that farmers will gain economically by using survey data to anticipate better how much and what kind of planting they should do or to take action in time to avoid large losses from crop disease. Despite some serious policy questions that such measures raise and possible side effects that may reduce the apparent benefits (which are considered below), this kind of application appears to have some merits.

But, failure to deal explicitly with the question of how, precisely, data will be utilized can lead to the kind of unfounded conclusion that is implicit in the following statement:

> A model (summarizing how farmers can use satellite survey data) is useful in showing how satellite-based information can be used, say, to increase crop production or to shift from one crop to another. In this manner, global food supplies can be maintained at sufficiently high levels even in the event of localized crop deficiencies whether due to natural or man-made causes. [2]

[1]One exception to this conclusion might involve data to be used in research, e.g., much of the oceanographic data. But even in this case, financial limitations alone would seem to require that research oriented data only be collected if the users (researchers) have a fairly good idea of what data they need and how it will be used.

What the statement seems to imply is that agriculture applications will lead to marked improvement in meeting global food needs. Though such an outcome is possible, it certainly is not probable. What isn't recognized is that the world's food problem is less one of inability to grow enough food than it is inability to surmount economic and political barriers so as to distribute food within and among nations according to need. If there is any doubt about this one need only to ponder the recent statement by the Secretary of Agriculture in which he suggested the desirability of holding 60 million acres of farmland out of production, in the U. S. for the rest of the century. [3]

Even more recently there has been a profusion of reports detailing the crisis in international wheat markets due to an overabundance of supply.[1] The irony of this state of affairs is that while the bounty exists millions of people—many thousands of whom are found right in the United States—suffer from inadequate food supplies. Though it would be foolish to adopt a pollyanna approach and assume that there will always be enough food, it seems a disservice to imply that an improved method of forecasting output and detecting crop stress will lead to more than a marginal contribution in solving world hunger problems. Something more than glib answers to such difficult issues is required.

A notable feature of some agriculture survey proposals is that they contain the best of both worlds. For example, they not only would assist farmers in raising output when shortfalls elsewhere are foreseen, they also assist farmers in knowing far enough in advance when bumper crops are coming so they can shift some of their resources into other crops. Superficially, the ability to perform such maneuvers would seem to enhance the market's ability to allocate resources efficiently. In practice, however, it is less clear that the elaborate array of anti-competitive barriers that are so much a part of the contemporary United States agriculture scene would permit many net benefits to filter down to consumers (and taxpayers), if in fact the barriers would even permit the adjustments.

There is another serious flaw in cases that foresee large gains, even to farmers, from either increases in output or shifts from one crop to another. Clearly if forecasts are accurate they can be of great value to farmers who act accordingly. But if many farmers act in a like manner, what is the likelihood that the implicit crop price forecast—which after all is what the farmer cares about—will remain firm? Obviously, cases that contemplate such adjustments in production, adjustments that in and of themselves serve to make the price forecast less probable, must assume that the final price structure will remain essentially as predicted.[2] This is indeed a heroic assumption for crops not under the pirce support program, and any alleged benefits that are based on it must be judged as highly speculative.[3]

Inadequate and incomplete attention to the nature and implications of data utilization are not confined to agricultural applications. One study has recommended an application to identify by means of satellite sensing and ground analysis of the data likely mosquito breeding areas in countries where malaria remains a serious problem. Upon identification of such areas aircraft spraying teams would be dispatched on spraying missions. Though space limitations preclude a detailed discussion of this case, it is perhaps sufficient to note that the study failed even to recognize that most of the malaria-ridden countries of the world are also among the poorest and probably would be hard put to finance an eradication program on the scale contemplated. Once again the failure to consider carefully the process by which inputs (data on mosquito breeding) can be transformed into outputs (mosquito eradication) leads to an exaggerated view of probable results.

[1] See, for example, "Commodities: World Wheat Surplus Yields Bitter Harvest," Business Week, August 9, 1969, pp. 25-26. In case one argues that this condition is merely an aberration, it should be pointed out that the long-term outlook for production is so good—except for farmers and officials charged with managing price support and production—acreage quota programs—that both India and Pakistan are expected to be exporting wheat by the mid 1970's. Ibid.

[2] Of course, if the crop in question was in the price support program and its price was at the support level then there would be no reason to expect a price decline.

[3] As a matter of fact, the wise and truly prescient farmer might be better off in such circumstances sticking with his initial plans as others make adjustments based on the survey data.

Notes on the Use and Misuse of Cost Benefit Analysis

Before proceeding with a case-by-case evaluation of proposed applications, some comments are in order about cost-benefit analysis and its relevance to earth resources survey applications. Cost-benefit analysis seems to be the sine qua non of the typical study of earth resources survey applications. In principle, such attempts to identify and enumerate the costs and benefits connected with an application are to be commended. Among the advantages of cost-benefit analysis "is that it forces those responsible to quantify costs and benefits as far as possible rather than rest content with vague qualitative judgments on personal hunches."[4] But there is the constant danger that mere quantification, regardless of the inferiority of the analysis that led to it, may be accepted as the last word. Like any other analytical tool, cost-benefit analysis can be misused.

A survey of representative studies of earth resource survey applications reveals a widespread tendency to use cost-benefit analyses inappropriately. As used in this context, inappropriately implies errors of commission and omission. A common error of commission is to report only the calculations that result from highly optimistic assumptions about the size and timing of benefit flow without giving sufficient attention to the possibility (if not probability) that things won't turn out so well. To postulate, as one study does, that our ability to transform satellite survey data, along with other measures, e.g., "seeding" the ocean so as to raise annual fish production, into the bountiful fish harvests contemplated there seems unwarranted if only because of the highly experimental nature of the application. At a minimum such an analysis requires a companion set of cost-benefit figures minimizing at least the flow of benefits received in the near term and, hence, reducing the present value of the project. Similarly, too many of the cost-benefit cases surveyed arrive at present values by means of discount rates that are at the lowest end of the range of possible rates.[1] Once again it seems only reasonable that the analysts furnish alternative estimates based on substantially higher interest rates.[2] Although these criticisms may sound petty to anyone not familiar with the theory that underlies cost-benefit analysis, their importance cannot be overemphasized.[3] "The purpose of cost-benefit analysis is to secure an efficient allocation of resources,"[5] and such is not likely if decision makers must base choices on unrealistic and improbable information.

No attempt has been made in the present study to estimate total costs for the system being proposed or to evaluate comprehensively the cost projections contained in the cost-benefit studies surveyed. Nevertheless, the tendency of many studies to minimize probable costs of data handling and interpretation is so egregious that it can't be ignored. It seems reasonable to assume that a multiple purpose satellite survey system is going to be generating immense volumes of data, much of which will not initially be in a form useful to, say, farmers or fishermen. Substantial interpretation will be required, and often the interpretation may be the most costly step in the process from point of acquisition to the point where the user receives the relevant information. To ignore or grossly underestimate these costs does not lead to cost-benefit ratios that can be used with great confidence.[4]

[1]For a good discussion of present value calculations and the question of appropriate discount rates see reference 4. For one cost-benefit study that is not guilty of the shortcomings noted, see Charles R. Frank, and Klaus-Peter Heiss, Cost Benefit Study of the Earth Resources Observation Satellite System: Grazing Land Management.

[2]The matter of what interest rate is proper in discounting is a controversial issue and clearly beyond the scope of this paper. The important point to note is that it would be desirable to furnish alternative present value calculations based on, say, 5, 10, and 15 percent interest rates.

[3]One study goes so far as to suggest that the uncertainty of payoffs requires that probability estimates should be attached to benefit estimates, Frank and Heiss, p. 54.

[4]Actually it is impossible to determine how many of the cost-benefit analyses dealt with interpretation costs. Inferentially, however, most appear to have glossed over the issue. This is unfortunate, all the more so because problems of doing all the interpretation required and obtaining interpreters to do the work may be so serious as to undermine the potential utility of the entire survey operation. Equally pressing is the need to begin planning a program to educate potential users, especially in the case of those applications where similar data have never before been available. The importance of the aspect of the program has been recognized in Frank and Heiss, p. 4.

To conclude this brief foray into the realm of cost-benefit analysis some general observations about what it can and cannot do are offered, if only because they have not always been recognized by the practicioners who have applied it to earth resource survey applications. First, cost-benefit analysis becomes a much less valid indicator of choice when market imperfections exist, e.g., crop price supports, because the value of the benefits to the direct recipient may diverge substantially—in either direction—from the value as seen by the community in general. Second, a cost-benefit ratio that appears to justify a project may be only an illusion if those who finance the project, i.e., taxpayers in general, do not share in the benefits in a proportion similar to their tax contributions. Unless great care is exercised under such circumstances, the result can be a situation where the eventual use of projects by beneficiaries who get something for nothing inflates benefits that serve to justify the projects in the first place.[5, p. 295] Third, it is the rare project that is devoid of substantial non-economic consequences, and where they exist they should be identified and considered in the decision-making process. In practice, however, they can't always be identified and many can never be dealt with quantitatively, all of which weakens the persuasiveness of cost-benefits figures. Finally, cost benefit analysis as applied to government projects must be utilized within the political areas, yet it is not capable of dealing with political costs and benefits, e.g., every relevant agency may "deserve" some space on the satellite for a pet project. All of which says that the methodology will "be twisted out of shape from time to time. Yet cost-benefit analysis may still be important in getting rid of the worst projects. Avoiding the worst where one can't get the best is no small accomplishment." [5, p. 298]

The tenor of the preceding discussion has been critical but, hopefully, it does not imply that much of the work done so far on the utilization and potential costs and benefits of earth resource survey data has been without value. Quite the contrary, despite shortcomings, the work is a useful first step. But it must be seen as just that, something provisional that requires refinement and elaboration. It is to be hoped that those responsible for planning an operational survey system will see these needs as being equally important as those involving further refinements in designing sensors, platforms, handling systems and the like.

Some Applications for an Operational Earth Resources Remote Survey System

Table 4.1 lists those needs applications of an earth survey system which were felt to be deserving of at least preliminary consideration on an operational system. A summary of each application is then given including remarks regarding its contribution to such an operational system. Each of these summaries is based upon more detailed studies of the relevant literature that is included in the bibliography. However, spatial requirements have precluded the inclusion of these more detailed studies in this report.

TABLE 4.1

Candidate Applications for Remote Sensing

Agriculture	Cartography
Forestry	Wildlife Migration Patterns
Air Pollution	Timber Inventory
Water Pollution	Geology-Mineral Applications
Ocean Mapping and Surface Characteristics	Management of Hydroelectric Dams

Fish Identification

Marine Transportation

Underground Water Inventory

Glacial Changes

Drainage Basin Characteristics

Disease Control-Malaria Eradication

Water Loss Along Irrigation Canals

Thermal Detection on Land

Grazing Land Management

Agriculture[1]

1. **Purpose of data** Remote sensing and data gathering in agriculture should improve international crop forecasts. Moreover, assuming the continued advance of sensors and crop signature analysis, early detection of disease, stress, and the degree of crop vigor may be possible. Progress in identifying crop acreage, estimating of harvests, and detecting disease epidemics should increase agricultural yields particularly in the developing countries.

2. **Technical feasibility** From a technical standpoint, it appears that methods of remote sensing will permit acquisition of meaningful crop information. Monitoring could be accomplished by near-infrared sensing. Several feasibility studies previously completed indicate the current state-of-the-art may permit crop monitoring for the numerous data needed to satisfy the varied agricultural information requests (see Appendix III).

3. **Economic justification** Many cost benefit studies indicate there will be multimillion dollar gains surpassing costs of R & D, launch, and data handling but these are based upon several implicit assumptions that do not appear to be readily defensible.

4. **Probability of success in achieving objectives** Current methods of data collecting in agriculture leave many inaccuracies and some areas with complete lack of information, particularly in developing countries. Efficiency in controlling agricultural stresses and increasing crop yields for a rapidly expanding world population should be aided via a remote survey system for agricultural monitoring and therefore this application could be included in such an operational system when technologically feasible. More immediate benefits can be expected from world crop inventories which, with appropriate ground truth, appear feasible in the near future.

Forestry

1. **Purpose of data** Future surveys of forests of the nation and world by remote sensing combined with extensive ground truth, could produce data on acreage, types, stress by fire and disease, growth rate, and tree size. Recreational and economic benefits are obtained from woodlands. As greater importance and more commodities are obtained from timber, this resource must be monitored and nurtured as a world agricultural crop.

2. **Technical feasibility** Currently it is possible to distinguish timberland from brushland from space. However, it is not clear whether forest types, tree size, growth density, and infrared idenfification of diseased trees can be determined by satellite sensing. Floods, fires, and hurricanes apparently can be remotely sensed and their destruction surveyed. Only periodic monitoring except for surveying fire and disease is needed to assure adequate data.

[1]For an extended discussion of the mechanism of remote sensing of vegetation and some of the associated problems, see Appendix III.

3. **Economic justification** Pertinent and informative publications in remote sensing of forestry problems are presented in the Bibliography. Aerial monitoring of a California forest fire reduced cost of control and destruction. Almost 11 billion acres of the world are covered by forests, directly producing many economic benefits as well as influencing climate, available water, and animal populations.

4. **Probability of success in achieving objectives** A world survey via satellite of forested areas is feasible for purposes of inventory and requires little repetitive monitoring. Frequent interval surveying would be needed for fire and disease control and encroachment by other destructive elements. Monitoring forest fires near densely populated areas could reduce fire loss since man is the primary source of this destruction. Some economic benefits should be realized regardless of the degree or intensity of forest surveillance, and therefore this application could be included in an operational aerial monitoring system.

Air Pollution

1. **Purpose of data** Both empirical and theoretical research is needed in the area of air pollution including studies of the spatial distribution of pollutants in urban areas (air sheds), their movements with changing atmospheric conditions and land use, and atmospheric models, which may lead to the prediction of pollution concentrations in order to determine appropriate policies for its control.

2. **Technical feasibility** There is evidence which indicates it is possible to identify smoke or steam plumes from spacecraft, identify their dispersion paths and to outline smog areas over urban complexes. This information is of value to identify needed air pollution control areas. However, prospects for identifying specific types of pollutants and their concentrations by satellite platform in the lower atmosphere is not promising.

3. **Economic justification** Given the limited amount of information on air pollution expected from satellites, their use for this purpose is of marginal value. Perhaps their greatest value is as a means of pictorially demonstrating the pollution problem which might stimulate public support of clean air legislation and enforcement of existing antipollution laws.

4. **Probability of success in achieving objectives** As just mentioned, satellite pictures could increase public support for clean air. However,, ground sensors already provide considerable information about the types and levels of concentration of pollutants in large urban areas. Of greater importance is the need to establish standards of air quality and develop appropriate governmental structures to insure their effective enforcement.

Water Pollution

1. **Purpose of data** As in the case of atmospheric pollution, identification of the types of pollutants, their concentration levels, the geographic areas affected, and the rates of pollutant dissipation would be of some value in developing regulations to central water quality for different uses and identifying violators of the regulations.

2. **Technical feasibility** While aircraft infrared photos have shown crude oil discharges and the spread of thermal pollution from specific sources, it is premature to argue that such information can be gathered from spacecraft platforms. It is unlikely that the resolution anticipated for the ERTS A or B missions would be adequate for the above purposes.

3. **Economic justification** Given the very modest probability of obtaining reliable data on water pollution from space platform under the present state-of-the-arts, such an application seems quite marginal.

4. **Probability of success in achieving objectives** As with air pollution, considerable is known about the types of pollutants, their concentrations and the water courses polluted in the United States. Of more pressing need is the development of standards of water quality for specific bodies

of water together with effective governmental organizations to enforce these standards. It is questionable that further data, no matter how good the quality, will be of much value in bringing about these results.

Ocean Mapping and Surface Characteristics

1. **Purpose of the data** The oceans are dynamic. Current and thermal line configuration change constantly and coastlines are not stable. Without synoptic data, small changes may be detectable but not gross changes, the latter being necessary for accurate charting and researching of the sea.

2. **Technical feasibility** Satellite sensors are most feasible for ocean mapping and surface characteristics because large areas can be covered per picture; the coverage is global; the coverage is fast and repetitive and there are synoptic geologic advantages for photo-interpretations.

3. **Economic justification** This is difficult to determine because of unknown factors. Reports of oil and mineral reserves in the continental shelf are numerous. If cheap methods are developed for extracting oil and minerals from off-shore locations, one-billion-dollar annual benefits are possible. Since, however, little of the continental shelf has been surveyed for mineral and oil deposits (only about 7%), the benefits are an unknown quantity.

4. **Probability of success in achieving objectives** This may be the area most applicable to satellite-remote-sensing. Because of the immense area to be covered and the need for iteration of coverage, it seems logical that only a satellite platform would be appropriate. The satellite remote sensing of oceans for cartographic data and surface characteristics appears to be highly feasible, if not for any great economic benefit, at least for research applications. It seems appropriate that data for this area of oceanography be collected from a satellite platform.

Fish Identification

1. **Purpose of the data** Little is known about the ecosystem of the oceans and, therefore, about the environment of marine fishes. Because of our ignorance, the feeding and harvesting of the marine fishes are not properly accomplished. The types of fish and their density and location related to the time of the year and their physical environmental factors are essential pieces of information for good management of the oceans.

2. **Technical feasibility** There is a need for satellite platform sensors, aircraft platform sensors and ground truth. Synoptic data (e.g., thermal lines, currents, etc.) can be detected and mapped from data acquired by satellite and more detailed, remote sensing (e.g., fish sighting, fish oil slicks, etc.) can be accomplished from aircraft. These data can be correlated with sea-surface samples taken by ships.

3. **Economic justification** The estimation of the density and the positive identification of the species of schools of fish is one of the essential aspects of the whole problem of fisheries management. School density estimates will permit managers of fisheries to determine the feasibility of sending ships into the area to fish the school and will reduce the number of poor fishing days considerably. Positive location of the school will reduce search time. Procedures on all phases of the fishing industry (i.e., dockside, at the factory and at sea) can be better organized and can be more efficiently performed. One estimate of economic benefit to the total world fishing industry of satellite remote-sensing applications is $1,560,000,000 per year between 1969 and 1989.

4. **Probability of success in achieving objectives** The probability of success appears to be good because little is known about the oceans, and because they are so immense and dynamic that synoptic, near-real-time coverage is essential. The feasibility of the fishing industry benefiting from remote sensing data of the oceans is uncertain but it is recommended that this type of operation be attempted. Perhaps appropriate sensors can be developed and tested on aircraft to detect and identify fish schools by type and, if successful, subsequently be tested on satellites.

Marine Transportation

1. **Purpose of data** As traffic in the oceans increases, a more sophisticated traffic control, navigation and search rescue system may become essential. Data such as shipping inventory and accurate forecasts of sea state and obstructions (e.g., sea ice) repetitively collected over large areas of the ocean will be necessary and will be most easily obtained through spacecraft-remote-sensors.

2. **Technical feasibility** Virtually all data can be collected via spacecraft sensors and correlated with or complemented by sea-surface obtained information.

3. **Economic justification** Studies on possible savings from better ship-navigation systems vary from $4.1 million to $160 million per year for ship owners throughout the world. Search and rescue operations for the world cost approximately $200 million currently, of which $150 million is for search procedures. It is estimated that at least $38 million of the search and rescue expense and at least one-quarter of the persons being lost, or 2,500 lives, could be saved by remote sensing techniques.

4. **Probability of success in achieving objectives** The success of obtaining an accurate inventory of marine shipping and aiding in search and rescue from a satellite platform is high if a transmitter-receiver system is developed and placed in use. Forecasting sea-state and ice surveillance appears to be highly probable from a satellite platform also. The conclusion is that acquisition of highly reliable and useful data by satellite is feasible in the areas of marine transportation and search and rescue operations.

Underground Water Inventory

It would appear that the possibility of adapting remote sensing techniques to the study of underground water supplies are limited. Optimistically stated, the contribution will be indirect and at the best problematic. Topographic maps indicating slope, land and/or rock type and area and type of vegetative cover should supply information relevant to computing the recharge rate of underground reservoirs. Since maps will be justified for a variety of purposes there is no good reason why they should not be used also for studying underground water supply.

Glacial Changes

1. **Purpose of data** The purpose of glacial change data would be to obtain measurement of area, volume, and movement of glaciers. This knowledge of glaciation cycles is relevant to a fairly wide variety of hydrologic and meteorologic problems and would appear to provide basic research data that may ultimately contribute to greater knowledge of man's environment.

2. **Technical feasibility** Present signal to noise ratios appear to preclude measurements of glacial depth, necessary for computing volume, as an operational aspect of a remote sensing system within the near future. Minute movement can be adequately charted by ground techniques. Gross, long-term movements could be charted by remote sensing.

3. **Economic justification** Justification of data collection about polar outlet glacial changes on a sheer economic basis seems unlikely. Aside from possible avalanches and floods from temperature zone glaciers that might threaten population centers, danger to human life seems minimal in relation to other phenomena.

4. **Probability of success in achieving objectives** It is unlikely that this application of remote sensing is justified at the present time.

Drainage Basin Characteristics

1. **Purpose of data** The purposes of obtaining data on drainage basin characteristics are to aid in the solution of problems associated with flood control, migration, water power, navigation, soil conservation erosion, pollution, recreation, wildlife management, and other hydrologic conditions.

2. **Technical feasibility** It is apparent that meaningful information on most hydrological applications would require vertical resolution of 2 to 5 feet for preliminary studies, while detailed analysis would require one foot or less in flat land. These specifications are beyond the capabilities of present available technology.

3. **Economic justification** While there appears to be significant economic benefits from improved data on drainage basin characteristics, it is not likely that much of this information could be obtained from satellite platforms and therefore economic benefits would appear marginal.

4 **Probability of success in achieving objectives** Although gross geomorphological data and updated topographical maps are reasonable expectations for a satellite oriented data collection system, more detailed data will continue to require low-flying aircraft and ground based sensors. Even assuming the satellite platform could obtain the necessary high resolution data, a major difficulty appears to be in the administrative structure for arranging data and making it available to a wider number of users. A satellite platform system to acquire drainage basin characteristics therefore appears to be of questionable utility.

Cartography

1. **Purpose of data** Users and uses of maps number at least in the thousands. Moreover, several users—such as regional planners— benefit from up-to-date maps of sizable regions. Much of Africa, Asia and South America is mapped to a small scale and some sections have never been accurately mapped, while many area maps of America are of limited value due to the lack of their being updated. Thus there appears to be a need to provide better and comprehensive maps to the multitude of users.

2. **Technical feasibility** There is little doubt that accurate maps of between 1:250,000 and 1:500,000 scale can be made from satellite platform.

3. **Economic justification** Because of the many uses of maps, an accurate cost-benefit analysis to determine the value of expenditures for them would be extremely difficult to accomplish. On the assumption that accurate and current world maps are meritorious and should be provided, it would be wise to obtain them at minimum cost. Considerable evidence suggests that the least cost method to get small to intermediate scale world maps and update them frequently would be from earth satellite pictures.

4. **Probability of success in achieving objectives** While use of satellite platforms for the purpose of world mapping appears to be a useful application, it will not eliminate the need for aircraft mapping unless or until the non-military sectors of the economy have access to cameras and other sensors capable of considerably greater resolutions than those at present. Large scale maps in the 1:100,000 scale or more thus will continue to rely upon aircraft pictures for their preparation.

Wildlife Migration Patterns

1. **Purpose of data** The purpose of the application is to obtain information on available grazing and browsing lands, on reduction of nesting and breeding areas due to natural or human factors, or weather patterns as they affect wildlife migration, and on wildlife inventory. This section is concerned only with land wildlife as fish are discussed in the section on Oceanography. The data would be used to aid the USDI, USDA, state conservation agencies, and foreign agencies in the protection of wildlife.

2. **Technical feasibility** Of the above types of remotely obtained data desired, the only one which does not appear feasible at this time is wildlife inventory. This could only be obtained implicitly from the other data or from low flying aircraft in the case of large game. The other information desired is quite similar to needed information in one or more other "needs applications" and should be easily obtained.

3. **Economic justification** Gross benefits for this application appear lucrative. However, the bases for these economic studies are not well documented and therefore the studies are somewhat questionable. A strong econimic case for this application will probably be difficult to achieve. The only rational basis for performing studies of this type are on the basis of potential savings over current practices. However, in many instances the current practices may be obsolete and therefore these savings are irrelevant. For this application of wildlife migration patterns it is felt that the esthetic benefits of preserving wildlife transcend purely monetary benefits. The value of such resources are not readily amenable to analysis.

4. **Probability of success in achieving objectives** It is believed that this particular application of an operational remote surveillance system has a relatively high probability of success.

Timber Inventory

1. **Purpose of data** This application is concerned only with inventory. Forest composition, insect and disease infestations, and forest fire are covered in the sections on Forestry and Disasters. The purpose of the proposed remotely obtained data is to provide information on the location and the extent of the forests of the world.

2. **Technical feasibility** This task appears to be quite feasible from a technical standpoint. The necessary resolutions are not difficult to obtain with remote sensors. A primary problem would be cloud cover in many areas of the world and if a satellite platform were used, many passes might be necessary over a given area in order to obtain a cloud-free view. If thermal infrared sensors were used this problem would not be as severe.

3. **Economic justification** The economic analyses of this application appear to be somewhat superficial and in many cases represent only estimates by professionals in these areas. However, the benefits presented are quite impressive and appear even more so when the less tangible side benefits to wildlife, recreation, water, and forage for livestock are included.

4. **Probability of success in achieving objectives** It is felt that this application stands a good chance of achieving both economic and social world benefits. Since the necessary frequency of coverage is only once every 10 - 20 years, a separate satellite system does not appear practical. However, the necessary data could be obtained with "on-board" sensors used to collect information for other needs applications. It is therefore felt that this application should be considered in an operational system.

Geology-Mineral Applications

1. **Purpose of data** The purpose of this data is to obtain, by means of color photography and radar imagery, regional geologic photo-maps that will aid exploration geologists in the search for new deposits of minerals and petroleum. A second purpose is to determine spectral properties of minerals and rocks at various wavelengths and in general to obtain a better understanding of the techniques of remotely identifying geologic structures.

2. **Technical feasibility** The first task mentioned above has been proven by means of aircraft and satellite platforms to be quite feasible technically. The second task is of a research nature and does not have established technical reliability.

3. **Economic justification** The economic analyses for this task are based upon questionable assumptions and have been difficult to substantiate. The research type of effort mentioned has no economic justification from an operational standpoint.

4. **Probability of success in achieving objectives** The overall success of this application on an operational basis is subject to some doubt. Certainly the research nature of the second purpose mentioned above is not operational by definition. The data needed to obtain regional geologic photo-maps could probably be obtained as a by-product of other "needs applications," for example, Cartography and Land Use Planning. Therefore, since the frequency of coverage is only once every 5 - 10 years this application could be a by-product of existing on-board operational systems.

Management of Hydroelectric Dams

1. **Purpose of data** The purpose of this application is to obtain advanced information about water flow into reservoirs in order to promote more efficient management of hydroelectric power generation and distribution.

2. **Technical feasibility** The types of data required appear to be rather difficult to obtain remotely unless surface sensors are employed; for example, information on snow depth, snow moisture content, soil moisture content, stratification of snow, river and stream levels and flow rates. However, information on snow area, snow surface temperature, and snow albedo can be obtained remotely with some confidence.

3. **Economic justification** This application does seem to have some rather lucrative monetary benefits. The economic analyses presented have been rather narrow in scope, however, the returns are nonetheless impressive on both a national and world scale.

4. **Probability of success in achieving objectives** Even though a large portion of the desirable information would be possible only with the utilization of surface sensors, enough meaningful data can be reliably obtained remotely to make this a promising application.

Disease Control-Malaria Eradication

1. **Purpose of data** The purpose of a malaria eradication program utilizing remotely obtained data would be to detect surface water conducive to the breeding of malaria-carrying mosquitos and to eliminate these mosquitos.

2. **Technical feasibility** The conclusion regarding the technical merits of this proposal are mixed. It is not clear whether or not the data to be collected by satellite are adequate to pinpoint probable breeding locations as well as breeding times. Nor is it adequately demonstrated that larviciding via aircraft on the basis of the satellite data and ground interpretation would eradicate most mosquitos. At this stage such assumptions are highly conjectural and require research before they deserve to become the foundations of an operational system.

3. **Economic justification** Although there has been at least one study on the economic benefits to be obtained from remote satellite sensing of areas conducive to mosquito breeding, this study does not offer a conclusive economic case for such an application.

4. **Probability of success in achieving objectives** The successful operation of this system of malaria prevention is highly questionable for the following reasons. It is doubtful if the remote sensors would be capable of detecting all the small ponds and all the relevant elements conducive to the breeding of malaria-carrying mosquitos. There is some doubt also that all countries possess the financial resources to undertake massive spraying programs. Therefore, if the project is to be undertaken, it should be viewed as a research effort and limited in its scope until its efficiency is determined. If it is eventually judged to be technically feasible, it should be evaluated on the basis of savings in such areas as sick days, lives and medical expenses that it will yield relative to similar kinds of savings that would result from other expenditures.

Water Loss Along Irrigation Canals

1. **Purpose of data** The purpose of this application is to use aircraft or satellite-based sensors to detect water losses along irrigation canals (i.e., phreatophytes) and to monitor these water losses on a routine basis. This information would presumably be used by hydrologists, agronomists, USDA, and state and local agricultural agencies to detect loss of water to "non-economic plants" and they would then take action to reduce these losses.

2. **Technical feasibility** This application has proven to be technically feasible by the numerous infrared photographs from Gemini satellites. It is believed that no major difficulties will arise from obtaining phreatophyte growth information from satellite in 500-mile orbit.

3. **Economic justification** No real quantitative economic analyses have been presented to show the actual costs to society of the "phreatophyte problem." If and when such analyses are made they should include the intangible benefits of the presence of phreatophytes; i.e., do plant growths along irrigation canals serve an important wildlife ecological purpose? Or might these growths serve as beneficial windbreaks in some areas or should they be allowed to exist for purely esthetic reasons? Who has not welcomed the sight of the green vegetation of such phreatophytes as willow and cottonwood trees along irrigation canals and streams in otherwise arid areas of the western United States? Must man be forced to justify all his societal decisions on solely economic grounds? These considerations should be included in cost/benefit studies of systems designed to detect and remove plant growths causing water losses along canals.

4. **Probability of success in achieving objectives** The detection of phreatophyte by means of remote infrared sensors has been proven to be one of the more technically reliable applications of a remote surveillance system. However, a valid case has not as yet been made that shows that an operational system of reducing water loss by reducing phreatophytes would unquestionably benefit society as a whole.

Thermal Detection on Land

1. **Purpose of data** Brief mention is given to the issue of detecting heat differences on land. Changes in volcanic structure, fault line shifts, earth crust materials, evapo-transpiration differences in vegetation types, and other heat sensor applications could be of value in predicting volcanic eruptions or earthquakes, discovering underground mine fires, or detecting plant damage.

2. **Technical feasibility** Isolated data and limited accuracy currently is obtained with ground data. High resolution is not required in most applications but data information could be obtained from surfaces such as vegetation. The reflectance spectral patterns are obtained from the first few inches of earth. Monitoring subterranean material is currently beyond technology.

3. **Economic justification** Data collected could be beneficial to agriculturalists, foresters, hydrologists, and others. Information obtained could be applied to increase maximum growth vigor and productivity of crops, but more R & D is required.

4. **Probability of success in achieving objectives** With adequate research and further technology innovations, success probably could be obtained by thermal sensing of earth resources in the near future.

Grazing Land Management

1. **Purpose of data** Three major uses of earth resources survey data have been proposed for the field of grazing land management. They are:

   1) Maps to supplement or replace existing aerial photography
   2) Analysis of range trends—season to season
   3) Seasonal forage forecasts

Base maps are currently an important aid in delineating range sites so as to assist in judging grazing potential, allocating grazing rights, and adjudicating disputes. Range trend analysis has as its major objective the detection of disease and insects in order that remedial action–most of which is already available and relatively inexpensive–may be taken. In addition, knowledge of range trends is useful in deciding areas for reseeding, soil stabilization, and weed control. Seasonal forage forecasts would be used by livestock operators in determining stocking rates.

2. **Technical feasibility** All three applications would use photographs, the latter two requiring multiple photographs of an area taken in different spectral bands. Success in each application is dependent on relatively high resolution, preferably 20 feet or better. In the case of forage forecasting, it is unlikely that any significant benefit can be expected with resolutions in the 100 - 200 feet range.

Resolution questions aside, the feasibility of base map photography is no problem. In the case of range trend analysis and forage forecasting, however, the feasibility remains doubtful until advances have been made in spectral signature identification from photographs.

3. **Economic justification** A rather good study of the economies of these applications has been prepared and the calculations presented there (which are probably on the conservative side) suggest that the total annual benefits for the United States would be less than $3 million even if resolutions in the range of 20 feet are obtained. Although no attempt has yet been made to estimate world-wide benefits, it seems clear that they would be far in excess of the United States' benefits–perhaps ten times greater.

4. **Probability of success in achieving objectives** Since maps are now being obtained by aerial photography and are being used by government agencies in managing grazing lands, it is reasonable to assume that satellite photos also will be used. In the case of range trend analysis, it is likely that attempts will be made to use the data by government agencies charged with managing the grazing lands. But just how useful the data will be won't be known until some attempts to use it have been made. Data for forage forecasting is less likely to prove beneficial. This project should be viewed as purely experimental, primarily because of the unknowns regarding spectral signature analysis.

Concluding Remarks

The original goal of this Phase II study was to conclude the analysis of needs with a list of those problem areas which are most pressing and into which insight might best be gained by an earth resource survey system. However, as the study has progressed it has become apparent that such a list would be extremely subjective and would do nothing more than reflect the opinions of a few. Therefore, no such "neat package" of major or minor areas about which data should be taken is presented. However, Table 4.2 succinctly covers many possible applications for an earth resources survey system by indicating the types of data needed, the necessary sensor platforms as well as the required resolutions and frequencies of coverage. The following discussion of tasks remaining is offered for provoking thought as to whether a specific data is really needed and should actually be collected.

There is need for research on data interpretation, forecasting, etc., including an examination of technical feasibility and economic costs. Research on data utilization is likewise required, including a survey of users, an assessment of possible economic, social, or political conflicts, an examination of foreign use potential, and means to resist vaguely substantiated pleas for mere "data collection." Inherent risks and uncertainties should be incorporated into cost-benefit analyses by preparing sets of estimates based on alternative assumptions; the incorporation of non-economic benefits and costs into analyses requires the identification of imponderables while resisting the fetish of quantification. Provisional packages based on important criteria important to decision makers can be prepared by consideration of alternative assumptions regarding the annual budget, and such factors as the political and economic payoffs. There must be eternal vigilance in guarding against the misuse of any particular analysis. Finally, the limitations of the system in solving needs must be recognized, realizing that data seldom constitute the **major** barrier in reaching objectives and that the larger barriers are economic, political and social.

TABLE 4.2

Data Needs and Specifications

LEGEND

A. Number Code

1. Completely satisfied by system
2. Partially satisfied by system
3. Not satisfied at all by system
4. Cannot determine at this time

B. System Components

AL - Aircraft over local region

ES - Global satellites for earth resources

GL - Ground based sensors (local)

RS - Global relay satellites

MS - Global meteorological satellites

NEEDS	SPECIFIC DATA NEED	PARAMETERS TO BE MEASURED	METHOD OF SATISFYING NEED BY SYSTEM	RESOLUTION	FREQUENCY
MAPPING INFORMATION					
Ocean Mapping					
	bottom topography	color	ES + AL[1]	100' (3' vertical)	5-10 years
	nearshore shallow water	water depth	ES + AL[1]	100' (3' vertical)	"
	shoreline location	emitted energy	ES[1]	100' (3' vertical)	"
	mineral resource location	bottom reflection	AL + ES[2]	(surface sensor)	"
		magnetic field strength		(surface sensor)	"
		gravitational field strength		(surface sensor)	
	sea slope	sea height	ES[2]	1000 miles (10 cm)	daily
	thermal mapping	temperature	ES[1]	10 miles (½degree)	daily
Land Mapping					
biological	soil types	(same as mineral info.)	ES + AL[1]		
	vegetation types	(same as mineral info.)	ES + AL[1]	300'	5-10 years
geological		(same as mineral info.)			
cultural	land use	high resolution photos	ES + AL[2]	25'	6-12 months
geographical	inland water location lakes, etc.	emissivity	ES + AL[1]	2'	5-10 years
FRESH-SALT WATER AT INTERFACES					
Coastal Fresh Water Losses into Oceans	thermal gradients	temperature	ES[2]	100' - 400'	9 days
	color gradients	color	ES[2]	100'	9 days
	sedimentation deposits	color	ES[2]	100'	9 days
NAVIGATION					
Air	accurate position of aircraft		RS[1]		6 hours or less
Sea	accurate position of		RS[1]		6 hours or less

NEEDS	SPECIFIC DATA NEED	PARAMETERS TO BE MEASURED	METHOD OF SATISFYING NEED BY SYSTEM	RESOLUTION	FREQUENCY
SEA STATE					
	surface temperature	temperature	ES[2]	1-10 miles (1°C)	twice daily
	current velocity(gross)		GL[2]	1-10 miles (½Kt)	weekly
	wave height		GL + ES[2]	1-10 miles (1-5')	twice daily
SNOW & GLACIER CHANGES					
Snow Changes	area of snow coverage		ES[1]	200-300'	1-4 weeks
	snow depth		GL[1]	(1")	"
	snow density		GL[3]		"
Glacier Changes	location & area		ES[1]	200'	"
	glacier depth		GL[2]	(1")	"
	density		GL[3]		"
POLLUTION INFORMATION					
Air	gaseous composition & concentrations		AL[2]	ppm ± 50%	1-30 days
	particulate & droplet compositions & concentrations		GL[3]	ppm + 50%	"
	locations of above		ES + AL[2]		"
Water (rivers, lakes, selected streams)	chemical pollution	chemical composition	GL[2]	50-100'	"
	physical pollution		AL[2]	50-100'	"
	thermal pollution		ES + AL[1]	50-100' (1°C)	"
	radiological pollution		AL[3]	50-100'	"
	electrical pollution		AL[3]	50-100'	"
Pesticides, Herbicides, etc. (land pollutants)	locations		ES + AL[2]	200'	1-30 days
	concentrations		ES + AL + GL[2]	200'	"
MINERAL INFORMATION					
Surface Features	soil type	color	ES[1]	200-500'	5-10 years
		water content	ES[1]	"	"
		texture	4	"	"
		topography	ES + AL[1]	"	"

NEEDS	SPECIFIC DATA NEED	PARAMETERS TO BE MEASURED	METHOD OF SATISFYING NEED BY SYSTEM	RESOLUTION	FREQUENCY
MINERAL INFO. (Cont'd)		elemental composition	4	200-500'	5-10 years
		mineral composition	4	"	"
		vegetational cover	ES[1]	"	"
		density	4	"	"
		temperature (subsurface)	ES[1]	"	"
	rock type	color	ES[1]	200-500'	5-10 years
		density	4	"	"
		elemental composition	4	"	"
		mineral composition	4	"	"
		topography	ES + AL[1]	"	"
		temperature (subsurface)	ES[1]	"	"
	fold & fault structure (includes earth-quake prediction)	movement	4	200-500'	5-10 years
		surface water content	ES[1]	"	"
		temperature	ES[1]	"	"
		topography (subsurface)	ES + AL[1]	"	"
	rock alteration zone	color	ES † AL[1]	200-500'	5-10 years
		water content	ES + AL[1]	"	"
		elemental composition	4	"	"
		mineral composition	4	"	"
		temperature (subsurface)	ES + AL[1]	"	"
Subsurface Features	magnetic fields gravitational strengths	miligauss miligal	AL[1] AL[1]	200-500' "	5-10 years "
DISASTER DATA					
Forest Fires	gross detection &	temperature	ES + AL[2]	100'	daily
	size	"	"	"	"
	direction of movement	"	"	"	"
	rate of movement		"	"	"
Search & Rescue	location of downed plane, survivors in ocean		ES[1]	50' (surface sensor)	daily
Flooding, Avalanche	surface area of snow		ES + AL[1]	1000'	daily
	snow depth		GL[1]	(surface sensor)	daily
	snow density		3	(surface sensor	daily

NEEDS	SPECIFIC DATA NEED	PARAMETERS TO BE MEASURED	METHOD OF SATISFYING NEED BY SYSTEM	RESOLUTION	FREQUENCY
DISASTER DATA (Cont'd)	snow temperature gradients		3	(surface sensor)	daily
	river & stream flow rates		GL[1]	(surface sensor)	"
	river & stream area		GL + AL[2]	(surface sensor)	"
Iceberg Detection	detection & location		ES + AL[1]	100-500'	daily
Volcano Analysis	eruption prediction	temperature	ES + AL[1]	500'	daily
FISH DENSITY & IDENTIFICATION					
	bioluminescence		4	100'	1-7 days
	temperature of water		ES[1]	1-10 miles(½°C)	1-30 days
	color of water		ES[2]	1-10 miles	1-30 days
	acoustic reflections		GL[1]		
	trubidity		GL[1]	1-10 miles	1-30 days
	fish oil slicks	maybe in uv.	AL[4]	100'	weekly
	visible sightings		GL[1]	100'	weekly
	sea vegetation		AL[2]	100'	weekly
	chlorophyll		AL[2]	1-10 miles	1-90 days
CROP FORECASTS					
(Wheat Corn Rice Etc.)	crop type		ES + AL[1]	100-200'	2-4 weeks
	status (density, maturity)		ES + AL[4]	"	"
	fallow acreage		ES + AL[1]	"	"
	boundaries of fields		ES + AL[1]	"	"
	rotation pattern		ES + AL[1]	"	"
	growth rate		ES + AL[2]	"	"
	vigor		ES + AL[2]	"	"
CROP STRESS DETECTION					
(Wheat Corn Rice Etc.)	disease identification		ES + AL[1]	100'	weekly
	insect infestation		ES + AL[2]	"	"
	weeds		4	"	"
	large storm & fire damage		ES[1]	"	"
	crop moisture (drought)		4	"	"
	soil temperature		ES + AL[1]	"	"
	soil moisture content		GL + ES[1]	"	"

NEEDS	SPECIFIC DATA NEED	PARAMETERS TO BE MEASURED	METHOD OF SATISFYING NEED BY SYSTEM	RESOLUTION	FREQUENCY
TIMBER INVENTORY					
(Selected Forested Areas of the World)	forest boundaries		ES + AL[1]	1000’	yearly
	density(crown closure)		GL + AL[2]	100’	”
	type of species		GL + AL[2]	”	”
(forest fires included under “Disaster”)	height of stand		GL[2]	”	”
	trunk diameter (ground survey)		GL[2]	”	”
	regeneration rate		3	”	”
WILDLIFE CONSERVATION					
	wildlife migration patterns		AL[2]		
	wildlife census				
	wildlife cover & food		ES[1]		
SOIL EROSION	topographic changes		AL[1]	10’	6 months
SEDIMENTATION PATTERNS	sedimentation deposits		ES + AL[1]	100’	annually
DRAINAGE BASIN CHARACTERISTICS					
Water Runoff	flow rate		GL[1]	(surface sensor)	2 hrs-weekly
	temperature		ES + AL + GL[1]	”	”
	acidity		GL[1]	”	”
	turbidity		GL[1]	”	”
	chlorinity		4	”	”
	radioactivity		4	”	”
Topography	relief mapping		AL[1]	2’-300’	1-10 years
DISEASE CONTROL					
Mosquito Breeding Conditions	distribution of surface water		ES + AL[1]	100’	weekly
	surface water temperature		ES + AL[1]	100’ (1°K)	weekly

NEEDS	SPECIFIC DATA NEED	PARAMETERS TO BE MEASURED	METHOD OF SATISFYING NEED BY SYSTEM	RESOLUTION	FREQUENCY
WATER LOSS ALONG IRRIGATION CANALS	phreatophyte growth		AL[1]	200-500'	yearly
THERMAL DETECTION ON LAND					
Geyser Location	thermal hot spots		ES + AL[1]	50-100' (5°)	6 months
Volcano Detection	thermal hot spots		ES + AL[1]	50-1000' (5°)	monthly
Mine Fires	thermal hot spots		ES + AL[1]	500' (5°)	weekly

4.2 DATA ACQUISITION

Overview of the TRIAD Observation System

System Description Raw data for the TRIAD system would be acquired on three levels; viz., by means of satellites and aircraft-borne sensors, and by reports obtained from men in the field, on ships, and untended sensors.

Satellite data, with one possible exception, can be considered low resolution data. Spatial resolutions would usually be on the order of 300 feet and no better than 100 feet under optimum conditions. Greater resolution is not required for this phase of data acquisition, nor is it desired from a data handling point of view since it will be global in coverage and in real time. Emission and reflection measurements show fine detail, integrated over a fairly large area, but the accuracy is poor if there are no ground truth reports and/or calibrating surface sensors which can be read out simultaneously with these measurements. The exception, mentioned above, arises from the fact that satellites would probably have the capability of reading out many accurate in situ instruments (e.g., stream gages, meteorology balloons, ocean buoys, etc.).

Data acquired via aircraft would in many cases be of high resolution. However, in this case, the data would most probably not be in real time, would cover only limited areas of interest, and would be strongly controlled by national policies as to when and how much of the data will be fed into the global coverage system.

Reports originating from investigators on land, waterways, and at sea would be essential for the accurate interpretation of much of the information obtained from satellite and aircraft sensors. This does not mean that they would have to cover all of the area being investigated, but rather only in statistically significant sampling areas. Again, like the information acquired by means of aircraft-borne sensors, the reports would most likely not be in real time and would be controlled by national policies.

Data collected over international waters and Antarctica by means of ship or aircraft-borne sensors would not be fed into the TRIAD system unless the TRIAD system has its own ships and aircraft or it can achieve good cooperation with the governments which own and control the ships and aircraft. Data from past and future satellite programs should also be supplied to the TRIAD system (e.g., from manned satellite systems, the ERTS, and the OGO systems).

Satellite Platforms Since the meteorological system enjoys tremendous international cooperation, is operational, and will be flying several geostationary and polar orbiting satellites in the future, and since the planned geosynchronous satellite navigational system will most likely also enjoy international cooperation, it is most desirable that these satellites be woven into the fabric of the earth resources program. This is especially true when it is realized there is space and power available on these satellites for supplementary equipment, and that the aforementioned systems would already be collecting much of the information needed for the earth resources program. Weather data in itself would be necessary for answering mnay inquiries made to the earth resources program, and the type of data collected would directly serve hydrology, ocenography, and fisheries, just to mention three areas. However, there may be some problem in merging the already existing meteorological system's hardware with the TRIAD system unless plans are made now to design the mid-to-late 1970's generation of weather satellites with this merger in mind. With respect to the navigational system, which is not yet in existence, the problem of merging should be relatively easy, but again, plans should be made now.

The satellite portion of the observation should contain a minimum of three geosynchronous (GSS) and two low orbiting sun-synchronous satellites (SSS). If the meteorology and navigational needs are merged with the TRIAD system's hardware, then the number of satellites would probably double.

The geosynchronous satellites should be employed to relay data in real time from sun-synchronous, low orbit, data collecting TRIAD satellites, to relay commands to the low orbit satellites, and to communicate some of the processed information to receiving stations throughout the world. Two of the geosynchronous satellites would have down-link capability and one could contain a computer for data reduction purposes. Two down-links and two ground collection stations would be required so that (a) one could serve as a backup system (ground stations must go down occasionally for preventive maintenance, if not for failure), and (b) multiple satellites reporting real time data may require two data links. (With meteorological low orbiting satellites in the system, there would be at least four satellites with real time information to be read out and sent down.) Any one of the geosynchronous satellites would be capable of telemetry contact with its two nearest neighbor satellites. If one of the geosynchronous satellites should fail, there would always be at least one down-link, there would always be an alternate route for data and command telemetry, and no more than one-third of the globe, if any, would be without coverage until a replacement satellite had been sent up. Use of geosynchronous satellites also avoids the necessity of using unreliable tape recorders in the low orbiting satellites.

Two nominally 500 n.m. high sun-synchronous satellites, redundant in equipment and orbit except that they are spaced 8 to 10 days apart in their track, would be employed to supplement the data collected by the meteorological polar orbiters: They should be sun-synchronized for midmorning (and mid-evening) at 9 to 10 o'clock. They would give coverage to about 70° of latitude and would give coverage to an area the size of the United States by two daytime and two nighttime passes per day. Imagery would be on 100 n.mi. wide swaths, and ground data collection system (GDCS) sensor readout would cover approximately 800 n.mi. wide swaths. The "exact" same track would be repeated approximately every 18 days by any one given satellite, thus 9-day coverage will be provided. One satellite should be on the sun side and the other on the dark side of the earth. Imagery overlap (side) would be approximately 10 percent at the equator and approximately 50 percent at 45° latitude.

The following discussion of a tentative array of satellites, sensors, and relay links is based upon the assumption that meteorology and navigational hardware will be merged with the TRIAD system. A minimum of six geosynchronous satellites is specified. (It is possible that a navigation system could be developed with as few as three or as many as 12 geosynchronous satellites. If a system of only three geosynchronous satellites were employed, the details of the system should still be workable.)

Geosynchronous Satellites The six satellites would be symmetrically oriented in the equatorial plane. All six would serve the navigational system (possibly by broadcast of omni radio signals), and each of the six satellites would have a data and command link with its nearest neighbor, as shown in Fig. 4.1. Satellites 5 and 6 would have a data and command link with two operations command centers, 11 and 12, in the southern part of the United States. Satellites 5, 7, and 9 would provide meteorological coverage in the following four ways: (1) Relay the data from the low orbiting meteorological satellites 3 and 4, (2) Provide continuous global visual and infrared (IR) cloud coverage and have instant automatic picture transmission (APT) capability. A redundant IR system for upwelling air measurement would probably also be included. (3) Provide a communication link with small weather stations, and (4) Provide global monitoring of precipitation by means of a long pulse radar system. Satellites 6, 8, and 10 would relay data from two orbiting TRIAD satellites which would be complementing two low orbiting meteorological satellites. This capability of relaying data from low orbiting satellites would back up the relay capability of satellites 5, 7, and 9, and vice versa.

On all six geosynchronous satellites there would be two small dish antennas for data and command link communications, two relatively simple polelike antennas for the navigation system, and a multipurpose 30-foot dish antenna. This 30-foot multipurpose, multifrequency antenna would serve the meteorological long-pulse radar system, and the data and command link to and from the low orbiting satellites and the ground. Communication with the low orbiting satellites could be on the same frequency but at different polarizations, or on different frequencies, preferably the latter. Spaces in the dish grid would permit the mounting of optical systems previously mentioned, and other devices such as a horn antenna for a down-link.

All Low Orbiting Satellites In a system where meteorology has been merged into the TRIAD system, there should be two different pairs of redundantly equipped satellites. One pair would contain meteorology oriented sensors in a nominally 700 n.mi. high polar orbit, and the other pair would be in a sun-synchronous, nominally 500 n.mi. high orbit and would carry sensors to complement those on the meteorology satellites.

1. **Meteorology Satellites** One of the low orbiting satellites would have a device to measure the index of refraction of several grazing-rays phase change. This would permit the calculation of the vertical distribution of atmospheric density.

One polar orbiter (there may have to be additional slave satellites) would act as an absorber and measurer of coherent radiation. Selection of proper frequencies of such radiation would permit gross atmospheric pollution measurements.

Both satellites would have a multichannel IR spectrometer for the measurement of the vertical distribution of temperature and moisture content above and between clouds.

A radar radiometer-scatterometer will be available in the near future and thus this device should be included on this platform. From the scatter return, it would be possible to infer sea state and, by continuous synoptic monitoring of sea state, it may be possible to infer something about sea slope. Some information on water, ice, and land interface or location would also be obtained. Direct altimetry readings of the accuracy required for sea slope do not look promising at this time. When operating as a microwave radiometer, it could measure sea surface temperatures and sea state with a lower power requirement, but there would be some limitations due to atmospheric attenuation and signal-to-noise ratio problems. If space is not made available on meteorological satellites for this instrument, it should then be considered part of the TRIAD satellite system.

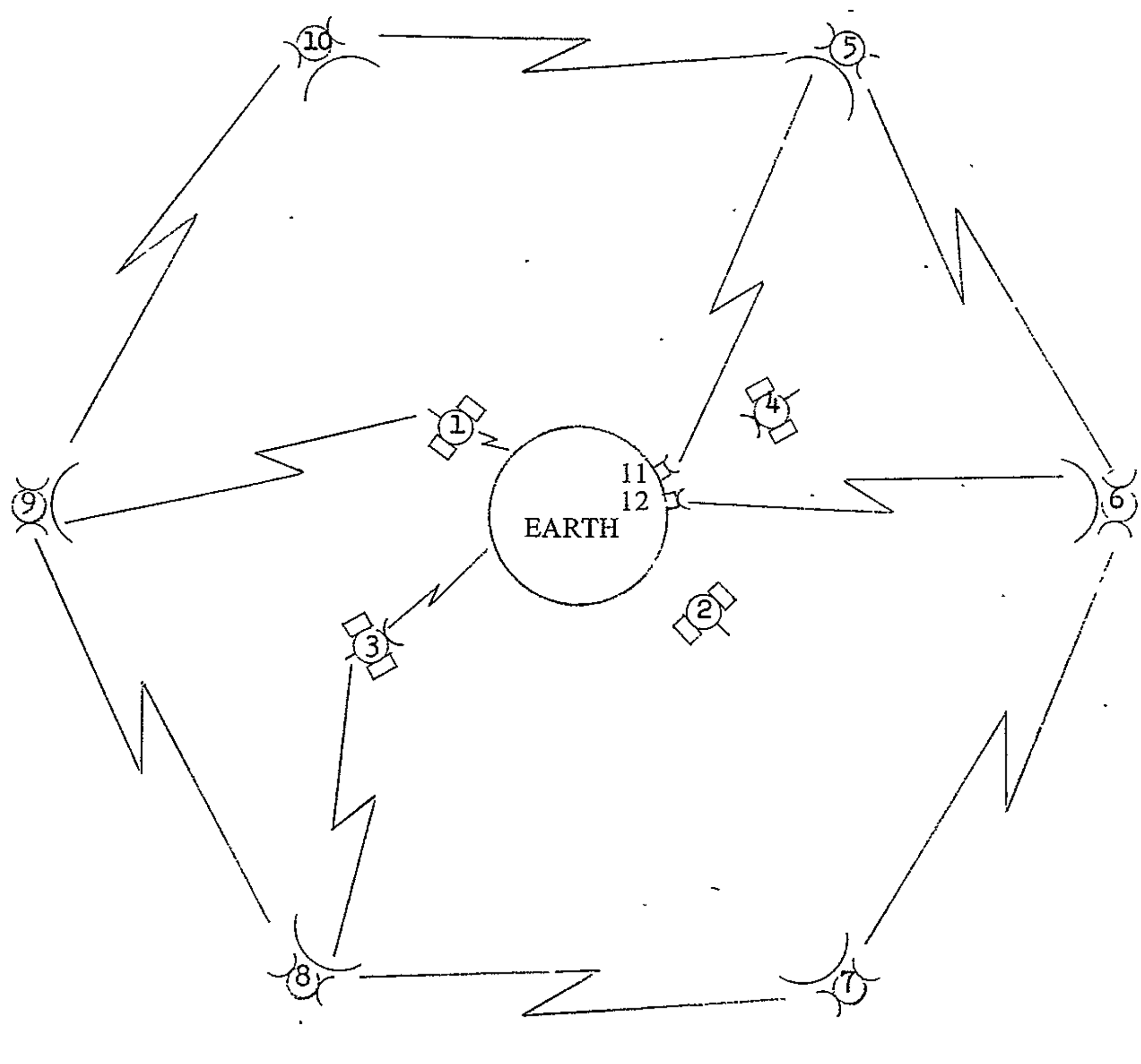
A device for the readout of high pressure balloon-borne sensors should be included on these satellites. It is recommended that this capability be included on all low orbital satellites.

2. **Earth Resources Satellites** The equipment on these two sun-synchronous satellites, 1 and 2, is as follows:

A wide band data and command link with the geosynchronous satellites; sensor readout equipment, including a computer-storage system to sort the information before relay to the geosynchronous satellites (to read out the ground data collection system, GSCS, sensors - buoys, balloons, etc.); an RBV-I.O. system of four or more channels (at present the RBV system produces higher resolution pictures and is more electronically manipulable than the multispectral scanners); a multispectral scanner system (approx. 10 channels) for signature analysis and for complete UV and IR coverage (this system is better than the RBV for spectral signature analysis); a small computer included at least for cloud discrimination if not for signature recognition.

It is expected that the mission lifetime for the polar orbiting satellites would be a 1 year minimum and a 5 year maximum. The geosynchronous satellites can be expected to have a minimum life of 5 years and a maximum life of 10 years.

Possible configurations for the earth resources satellite and for the geosynchronous satellite are shown in Figs. 4.2 and 4.3, respectively.



1 and 2 = TRIAD Supplementary Sensor Satellites
3 and 4 = Meteorology Satellites
5 thru 10 = Navigational, Meteorological and Data and Command Relay Satellites

Fig. 4.1 Geometry of relay net

Relay Satellites Compared With Ground Station Network

A basic assumption was made in Chap. 3. It was concluded there that the weakest link in any global system would be the on-board data recorders. The reliability of present and near-future recorders appears dubious for long-duration missions. As a result, on-board recorders have not been considered part of an operational system.

As a result of this decision, real time global data acquisition becomes necessary. This could be accomplished using a global ground station network or by using a limited number of ground stations and relay satellites. In making a decision, a number of factors must be considered.

The existing Stadan, Mini-track, and manned spacecraft tracking networks have been reviewed to determine their location, equipment, interconnection links, and usage. It is apparent that large voids exist for providing global coverage for polar orbiting satellites. Due to the large bandwidth requirements, it is also obvious that X and S band links must be considered. In general, it can be concluded that with the existing stations, real time data transmission could only occur on the average for less than half of the orbit period. To fill this void it would be necessary to construct new ground stations in foreign territories. A global system based on multiple foreign ground stations has a number of advantages and disadvantages. Such a system would provide an inducement for seeking foreign investment to help defray the cost of the system, and would give the foreign governments direct access to and a control of the data acquired over their boundaries. However, if a foreign station refused to release the data it acquired, then the global aspects of the system would be impaired. Even if additional stations were built at all desirable land locations, there would still be gaps in the system over ocean areas. It also might be difficult to prevent nonsubscribing countries from obtaining the data at the expense of building their own ground stations. On the other hand, however, subscribing countries could exert economic and other pressures to force nonsubscribing nations into assuming their share of the cost. The major disadvantage of this system would be the lack of centralized control.

The alternative approach is to consider the use of a relay satellite system. It is felt that such a system is feasible in the near future, even though numerous technological problems are yet to be solved. The major problem envisioned is the ability of a polar orbiting satellite to point its antenna(s) toward and tract geostationary relay satellites. It appears that two antennas mounted symmetrically on the satellite sides perpendicular to the orbit motion would require three-axis gimbaled mountings. The inertial axis would be continuously pointed to a fixed reference (i.e., the sun) and the primary and secondary axes would be controlled by monopulsed autotracking. The acquisition of any given relay satellite would require on-board programing which would be updated periodically from the control center via command telemetry. The wide-bank link from the polar orbiting earth resources satellite to any geosynchronous satellite could be implemented by a small quad helix transmitting antenna on the polar satellite and a rather large dish receiving antenna on the geosynchronous satellite. Such large deployable structures would be mechanical monsters but are within present technological limits.

Data relay satellites in either true geosynchronous or pseudosychronous inclined orbits have a number of possible applications. Worldwide navigation, traffic control, communications, and tracking are just a few. The polar orbiting meteorological satellites are well established but must rely on recording devices at present. Since the data that the meteorological satellites acquire are pertinent to earth resources, an attempt has been made to integrate them into the overall system. Certain sensors relevant to oceanographic needs could be combined with existing sensors on the meteorological platforms. The previously mentioned geosynchronous relay net of six (or more) equally spaced satellites has a number of advantages. Such a system could satisfy a variety of users, earth resources being just one.

Since entire global coverage, with the exception of polar regions, can be obtained with three geosynchronous satellites, the meteorological satellites could use three geosynchronous satellites for real time relay while simultaneously the lower orbiting earth resources satellites were relaying with three different geosynchronous satellites. In addition, all six or more geosynchronous

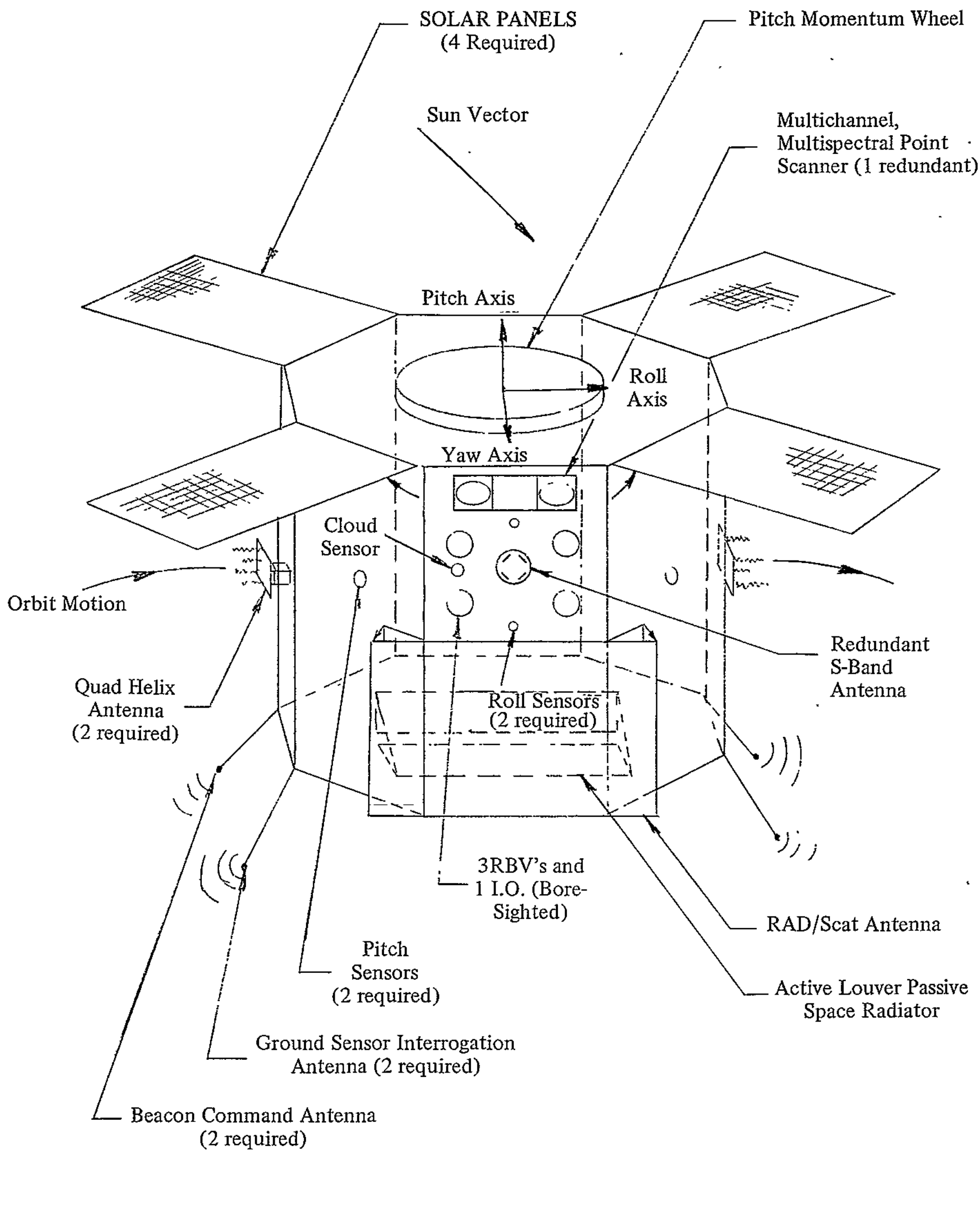


Fig. 4.2 Possible configuration for TRIAD remote sensor satellite

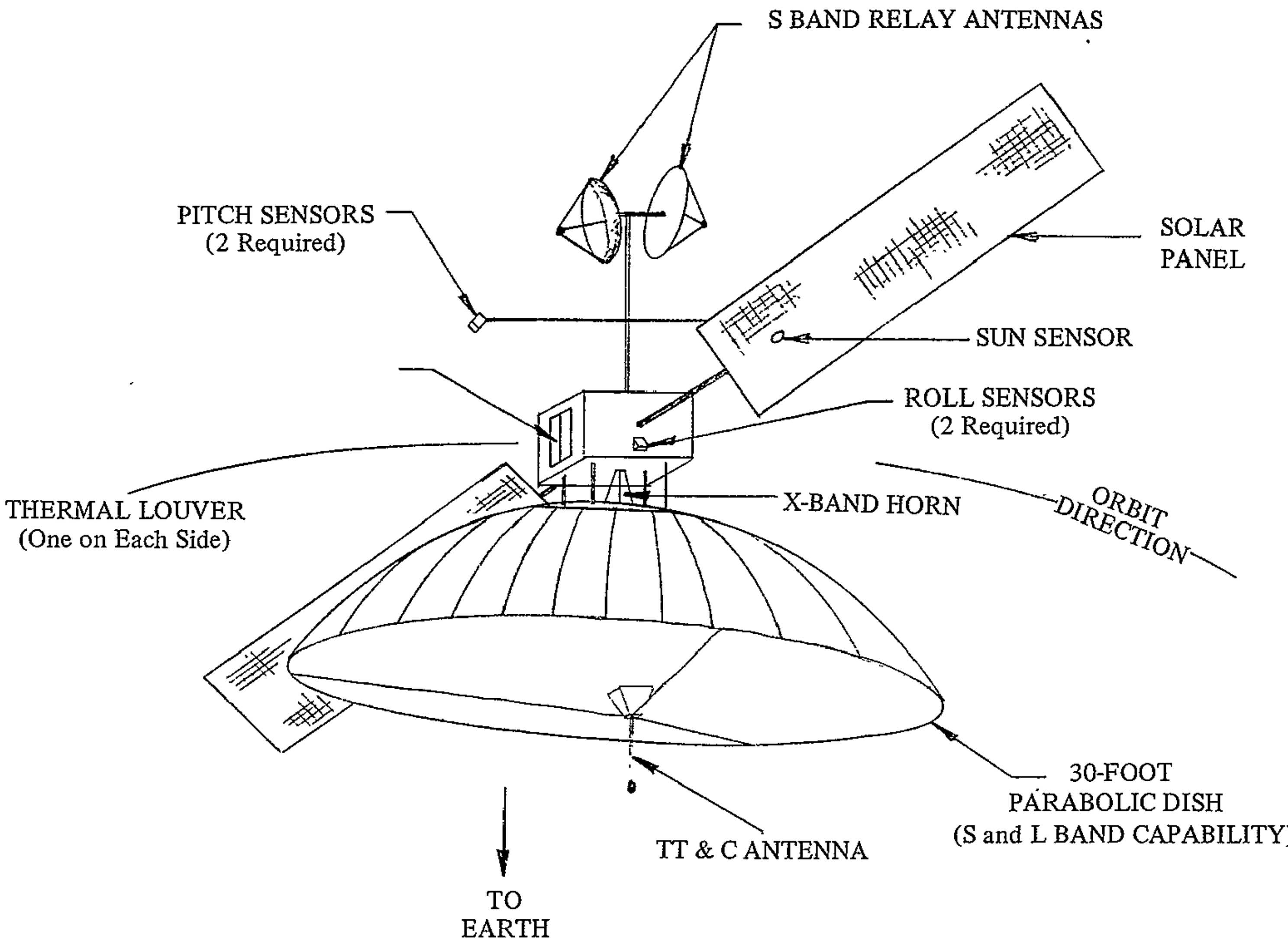


Fig. 4.3 Possible configuration for TRIAD
geosynchronous-data relay satellite

satellites could provide global navigation and tracking capability. With such a system, centralized control and acquisition of a wide variety of data would be provided with two ground stations located in the southern part of the United States. No attempt is made here to locate these stations, but consideration should be given to existing facilities having, or being adaptable to, S and X band communication capability. This system would supplement the existing and future meteorological satellite system and would in no way interfere with ESSA programs. The relay net would expand the meteorological system into a real time global system and provide additional sensors at geosynchronous orbit. Due to the higher orbits (700 to 900 n.mi.) of the meteorological satellites, consideration should be given to including a radar radiometer/scatterometer on these satellites to assist the oceanographers. The navigational and control net would require consideration to be given to global coverage such that at any given location a minimum of three satellites would be visible. Depending on the latitudes to be covered, either additional equatorial, synchronous satellites or additional geosynchronous satellites in low inclined orbits would be required for this application. No attempt has been made here to design such a system, but it should be considered a part of an overall global system involving relay satellites.

Many obvious problems must be solved in the design of a relay satellite net. The number, deployment, and spacing of antennas for the various data and command links, the power requirements, on-board storage and computation, modulation techniques, pointing and beamwidth accuracies, station keeping, and tracking are but a few of the engineering problems. Such engineering problems, however, are solvable.

In conclusion, the multipurpose data relay net has been selected because it provided multipurpose, centrally controlled real-time data acquisition. It would supplement existing systems (e.g., ESSA and COMSAT) and provide global earth resource data as well as navigation and traffic control capability. International control could be obtained by providing multi-nation participation at the centralized data acquisition and control center. It is felt that international cooperation will not be difficult as long as the global system does not yield high resolution data which would be a threat to the security of a participating nation. The economic benefits to a participating nation would be the system's major selling point. At a later date, three of the geosynchronous satellites could be used to provide down-link real time data, and individual nations could build and staff their own receiving stations either individually or in a consortium. However, the United Nations or some other international body would still be required for policy administration, as has been discussed in Sections 3.3 and 4.4.

Preliminary Design of Earth Resources Satellite Subsystem

Orbit Considerations Since an earth resources mission will involve visible imagery, a circular, sun-synchronous, polar orbiting satellite has been chosen. The mechanics of the sun-synchronous orbit are the same as those for any other circular orbit. The sun-synchronous orbit is unique in that for selected combinations of altitude and inclination the orbital plane precesses about the earth's polar axis in the same direction and at the same rate as the earth's annual revolution about the sun. This precession of approximately 1° per day results in a nearly constant angle between the orbital plane and the sun vector, so that the subpoint track of the spacecraft on the earth's surface receives nearly the same solar illumination each orbit. The unique mechanics of this orbit are a result of the spheroidal shape of the earth which causes variations in the earth's gravitational field. This bulge at the earth's equator causes the orbit plane to inertially rotate at a constant rate about the north-south geographic axis. Thus, the line of nodes will rotate constantly in the equatorial plane - in a westward direction if the orbit inclination is less than 90°, and in an eastward direction if the inclination is greater than 90°.

The geometry for sun-synchronism is determined by the relation

$$\cos i = 4.128 \times 10^{-14}\, a^{7/2} (i - e^2)^2$$

where

i is the orbital inclination in degrees

a is the orbit semimajor axis in nautical miles

e is the eccentricity.

The geometry between the sun and the orbit plane defines the "o'clock angel." It is the angle between the ascending node and the "mean sun," a fictitious sun used for defining Greenwich mean time. This differs from the "true o'clock angle" which is the angle between the ascending node and the projection of the sun vector in the celestial equator. The "true o'clock angle" is not constant because the orbit of the earth around the sun is inclined to the equator and is elliptic. Thus, for a given altitude and inclination, the sun angle varies with season for different o'clock angles. This information, in conjunction with orbital injection errors, is necessary to establish an acceptable launch window for a desired sun angle-range.

Due to the earth's rotation, the orbit lines of nodes regresses westward with respect to the earth. The rate of regression and orbital period determine the separation of successive subtracks which, in turn, determines the sensor swath width and overlap between adjacent orbits.

In selecting the specific orbital parameters for a circular, near-polar, sun-synchronous orbit, three parameters are basic. If the orbit altitude, time of ascending node, and swath width (or instrument package field of view) are known, then most of the other orbital parameters follow. A 500 n.mi. orbit has been selected after considering the various trade-offs associated with launch vehicles, instruments, attitude control, energy requirements, mission duration, and thermal control. The inclination for this orbit is 99.1°.

The launch vehicle most suited for this orbit would be a thrust-augmented Thor-Delta with a TE364 third stage. This vehicle is capable of placing 1,220 pounds in a 500 n.mi. orbit. The three sigma injection errors associated with this vehicle are: velocity, 52.5 fps; altitude, 6.5 n.mi.; flight-path angle, 0.6°; inclination, 0.75°. The total velocity error, ΔV, is 408 fps. These injection errors will cause a variation from the desired nodal precession rate. This variation will result in an o'clock angle drift over the mission lifetime.

In a sun-synchronous orbit, the orbit plane maintains a relatively constant angle with the sun vector, so that the ground illumination pattern in the sensor fields of view remain relatively constant. However, there are seasonal variations in the solar illumination angle due to the eccentricity of the earth's orbit around the sun and the inclination of the earth's polar axis to the ecliptic plane. This seasonal variation is approximately 25°. As a result of these considerations and user requirements, a 9:30 a.m. orbit was chosen.

With the selected swath width, overlap, and altitude, it would take 18 days for complete coverage of the earth with a degradation to 23 days at the end of 1 year. The orbit period becomes approximately 104 minutes and yields a 25.8° separation in longitude between successive ascending nodes.

To provide 9-day coverage, two identical satellites would be placed in the same orbit. This would require two separate launches from the Western Test Range or a single launch using a larger booster in the Titan IIIB/Agena-D class.

Major injection errors in orbit and inclination would be removed using a hydrazine thruster with spacecraft orientation command from the ground for each maneuver. If two satellites are launched on one vehicle, sufficient thrust must be onboard for obtaining the desired separation. It appears that two separate launches would be more economical and desirable.

The geosynchronous relay satellites would be launched Using a Titan IIIB/Agena-D which will place a 2,000-pound payload into 19,323 n.mi. geostationary orbit.

Sensor Packages As a result of the specific data needs elucidated in Section 4.1 and the sensor evaluation study of Section 3.2, the following selection of instruments has been chosen for the satellite platform.

Three return beam vidicons have been chosen to provide three spectral channels of information in the visible region of the spectrum: 0.48-0.58; 0.63-0.73; and 0.71-0.81 microns, respectively. In addition, one image orithicon would be included for information in the 0.76 to 1.0 micron region. These cameras would be remotely calibrated and provide an electrical output at the ground station which can be corrected for geometric distortions before being placed on film for interpretation. The system would provide 100- to 300-foot ground resolution, depending on contrast. This is based on a 500 n.mi. orbit and a 100 n.mi. swath width. The cameras and associated electronics would require 200 watts average power and weigh a total of 120 pounds. The total sensor package would require from 3 to 4.5 MHz bandwidth, depending upon the number of TV lines. It is expected that the data obtained from these cameras would provide major information for users in the areas of geology, agriculture, forestry, cartography, hydrology, and geography. Minor information would be available for users in the areas of oceanography and land use.

A multichannel (7 minimum; signature analysis and pattern recognition research will be necessary to define the exact number), multispectral point scanner would be included to yield information in the visible, near-infrared, and thermal infrared regions. The infrared detectors would require cooling which may best be supplied by the use of heat pipes and a space radiator. Ground resolution attainable from a 500 n.mi. orbit becomes a function of the detectors, diffraction limits, and optics. It varies from 100 feet in the visible to 400 feet in the thermal infrared. Such a 7-channel system would draw an average power of 70 watts, weigh 130 pounds, and would require a 5 MHz bandwidth. This device can also be calibrated in flight and yields good registration and excellent photometric accuracy. The data would supply information for the areas of agriculture, forestry, hydrology, cartography, oceanography, and geography.

A microwave radiometer-scatterometer has been chosen because it is both an active and passive system capable of operating at a single frequency (i.e., 10 GHz), thus time sharing the same equipment. The electrically steered phased array antenna would require 1 square meter of area and weigh 25 pounds. The associated electronics would require an average power of 26 watts and weigh 30 pounds. The bandwidth required would be less than 1 KHz. The data from this instrument would have large usage in the areas of oceanography and hydrology. Since resolution is not a critical factor in oceanographic applications, this sensor could be incorporated into the meteorological instrument package if space and power were made available on one of the meteorological satellites.

The satellite platform would house a data collection system capable of interrogation of multiple ground-, balloon-, and buoy-based sensors; this data collection system is called the Information Retrieval and Location System (IRLS). The spacecraft would have a memory for storing a series of remote station interrogation commands. Upon data acquisition from a remote station, the spacecraft would transmit the address code of the station and the requested data in a coded format. The power and weight requirements would depend upon the number of stations to be interrogated. The major users of this sytem would be the areas of hydrology, oceanography, and meteorology.

The total satellite sensor package would require approximately 400 watts of average power, weigh about 300 pounds, and require a 10 MHz bandwidth per satellite.

A cloud detector and on-board logic device would be included. If the meteorological input via command link and the cloud sensor output concur, then the visible imagery would be taken. This concurrence is necessary to prevent a false alarm from the sensor.

Attitude Control System The disturbing forces which tend to produce torques about the center of mass of an orbiting satellite arise from many causes. The major contributors that are considered include gravitational forces, the sun's radiation pressure, atmospheric drag, reaction torques from antenna motion, bombardment by meteoroids, and the effect of the magnetic and electric fields about the earth. These torques can be classified into three types: short lived torques, torques which vary in an oscillatory manner as a result of the orbital motion of the satellite about the earth, and torques which tend to produce a persistent turning moment about the center of mass of the satellite.

A portion of the solar and aerodynamic torques are considered cyclic, while the remaining portion remains constant with respect to a body fixed coordinate system. The magnetic torques are considered cyclic with the orbital frequency in the body fixed reference frame. The gravity gradient torques may be secular or cyclic, depending upon whether the cause for the principal axes deviation is cyclic or secular with respect to body fixed coordinates. The resulting ratio of fixed to cyclic torques thus depends upon the satellite configuration and the size of the solar array.

The mission and sensor pointing accuracy requirements dictate the attitude control specifications. A system is desired which would orient the earth-facing satellite with a stabilization in yaw, pitch, and roll directions to within 0.75°. The stabilization rates should be less than 0.05° per second.

The desired control system would consist of spin stabilization about the pitch axis of the satellite by means of a rotating flywheel. Orientation of this flywheel would be maintained along the orbit axis by the use of magnetic torquing. Such a system would require attitude data readout and corrections on the average of once a week. The system would include earth horizon sensors for pitch and roll data acquisition, a nutation damper, an attitude acquisition sensor, and a sun sensor.

This system should weigh less than 75 pounds and draw less than 10 watts steady state.

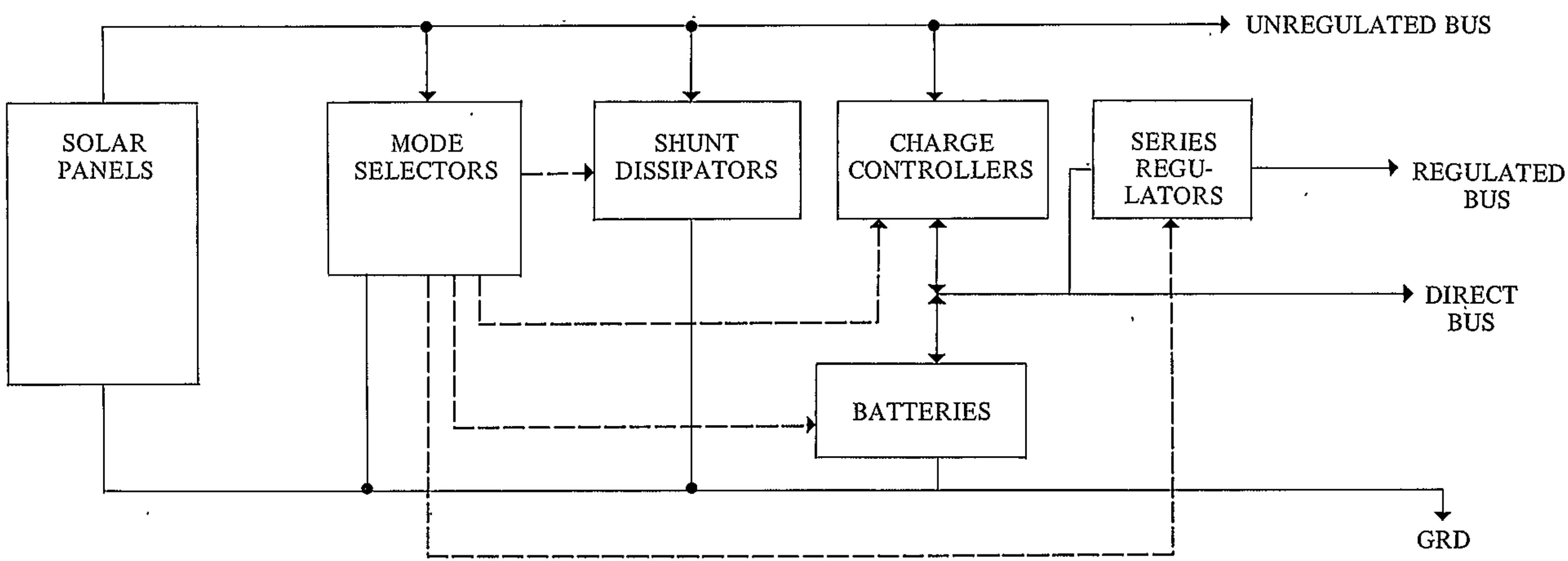
Thermal Control System The satellite temperature would be controlled by a partially active and passive system which would produce a thermal balance between the heat inputs and the heat radiated from the satellite. The satellite would be subjected to a relatively constant heat input from the sun over the range of sun angles anticipated. In addition, transient sun loads and power dissipation cycles are to be anticipated. The selection of insulation and conduction paths would be such that all components will experience an environment in the range of 0° to 30° C during the lifetime of the mission.

Combinations of louvered radiators, heat pipes, insulation, and thermal reflectance coatings should be capable of satisfying these needs. In addition, radiator space would be required for sensor cooling.

Power System A study of the types of power systems has led to the conclusion that nuclear power systems, because of their radiation and weight problems, would not be feasible for a TRIAD operational system. Consequently, the solar panel-storage battery system is proposed as the power supply for the various satellites in the TRIAD system. Since a number of different satellites with different duty cycles and loads are included in the TRIAD system, only a general power supply and control system will be described here.

Fig. 4.4 shows the proposed energy system containing three basic subsystems consisting of the solar panel array, the power supply control, and the batteries. The system is a solar cell-rechargeable battery power supply containing a regulated bus, an unregulated bus, and a direct bus from the batteries.

The solar panel array converts the sun's incident energy to electrical energy. The shunt dissipators prevent the array bus voltage from exceeding prescribed limits by shunting the solar panel array current not needed to recharge the batteries or supply the equipment loads. The



——— Supply Current
– – – – Control Signals

Fig. 4.4 Proposed energy system

mode selector controls the operation of the shunt dissipators, the charge controllers, and the series regulators. The batteries are used to supply power to the spacecraft during eclipse periods and also to supply peak loads at the peak demand periods during the satellite day. The charge controllers provide protection of the batteries by limiting charging currents to proper levels during charge and overcharge periods. The series voltage regulators maintain the voltage on the regulated bus within allowable limits during variation in load current and input voltage. In order to provide adequate reliability of the power system, redundant pieces of equipment would be necessary. At least two batteries should be provided with separate charge controllers to make them functionally redundant. The voltage regulators and mode selection electronics should also be redundant for the extended lifetime of the system.

The satellites are equipped with telemetry and command channels which would relay satellite housekeeping information. In the power supply, a number of items would be monitored with the telemetry system. Some of the required power system housekeeping duties are listed in Table 4.3. The proper protection of the circuits from overload and transients should be supplied with reset control capability in the telemetry system.

TABLE 4.3

Power System Telemetry

Parameter description	Telemetry*
Mode selector current	A
Battery charge current	AD
Battery voltage	AD
Solar panel current	AD
Solar panel voltage	AD
Unregulated bus voltage	AD
Regulated bus voltage	A
Shunt dissipator ON/OFF	A
Shunt dissipator temperature	AD
Battery temperature	A
Solar panel temperature	AD
Regulator selection	A
Charge current ON/OFF verification	A
Power system electronics temperature	D
Mode operation control	D

*A - analog
D - digital
AD - analog and digital

In order to finalize the design of the spacecraft power system, it is necessary to establish the duty cycle and the power requirements of the payload. It is also necessary to make an injection mode performance analysis in order to maintain the energy balance and supply the system requirements prior to deployment of the solar panels.

Role of Aircraft Subsystem

In order to fulfill TRIAD objectives, an aircraft program is essential as part of the total effort. It is important to state at the start that "space and aircraft systems are inherently complementary and not competitive . . . ," a conclusion supported by a Cornell study[6] for USDA. Just as aircraft observations have not rendered field measurements by men on the ground obsolete, a system of earth-orbiting satellites will not render obsolete the operational use of aircraft for producing valuable data. Obviously, sensors onboard satellites cannot collect high-resolution data comparable to data available from aircraft altitudes. Man on the ground has always been able to see the leaves and trees; with aircraft he gets a much better look at the trees and part of the forest and, now with the satellite, he gets a look at the entire forest.

In particular, for the TRIAD system, aircraft would provide the facilities for detailed exploration of particular areas or patterns of behavior. Use of aircraft would allow more repetitive coverage (daily, hourly, continuous) for a particular selected area than the previously mentioned orbiting two-satellite system that has an 8- to 10-day period. In addition, higher resolution of these particular selected areas would be provided by aircraft coverage.

Hard film photography should be used as the sensor for satisfying user needs for high resolution and short-term repetitive coverage of particular areas or patterns of behavior. Aerial photography is a proven, well-developed technique and would continue to be needed to seek and measure the earth's resources. The aircraft's photographic instrument package should include a high resolution panoramic camera, metric camer, ultrahigh-resolution camera (telescope), and multiband cameras so that all individual user needs can be fulfilled.

Some users [7, 8, 9] have found useful application in high-resolution side-looking airborne radar, commonly called SLAR. SLAR brings to remote sensing such valuable attributes as:

(1) All weather usefulness,

(2) Around-the-clock application,

(3) Ability to penetrate vegetation and provide geologic terrain maps, and

(4) Possible signature identification by dielectric properties.

However, the power penalty caused by high altitude makes it clear that a synthetic radar sensor must be used at as low an orbit as possible. Fig. 4.5 shows the effects of antenna size, orbit, altitude, and swath width on power requirements for the radar. Application of the radar for earth resources measurements should be delegated to aircraft because of the large power requirements of the radar. Low-power (200 watt) satellite systems, with less than focused antennas are available, but the lack of resolution and proven applicability limits the use of radar to aircraft.

Within a realistic framework of technology, user needs and economic constraints, other remote sensing instruments should be considered in the TRIAD aircraft system in addition to the hard film photography and SLAR. A microwave radiometer-scatterometer, gravimeter, magnetometer, spectrometer, laser altimeter, and/or an absorption spectrometer could all be added to the instrument package of the TRIAD aircraft. These instruments are presently either already operational or in various stages of development of becoming operational. The TRIAD aircraft should only be packaged with those instruments that are operational and within the constraints specified previously. Research and development necessary for new remote sensing instruments is not within the framework of the TRIAD system and should be supplied by outside contractors such as NASA.

The aircraft system should be utilized by the TRIAD system to involve and train foreign nationals in earth resources surveys. Katz [11] recommended this approach, and it has been done by NASA with Mexico and Brazil in 1968-69 with excellent results. Nationals from foreign

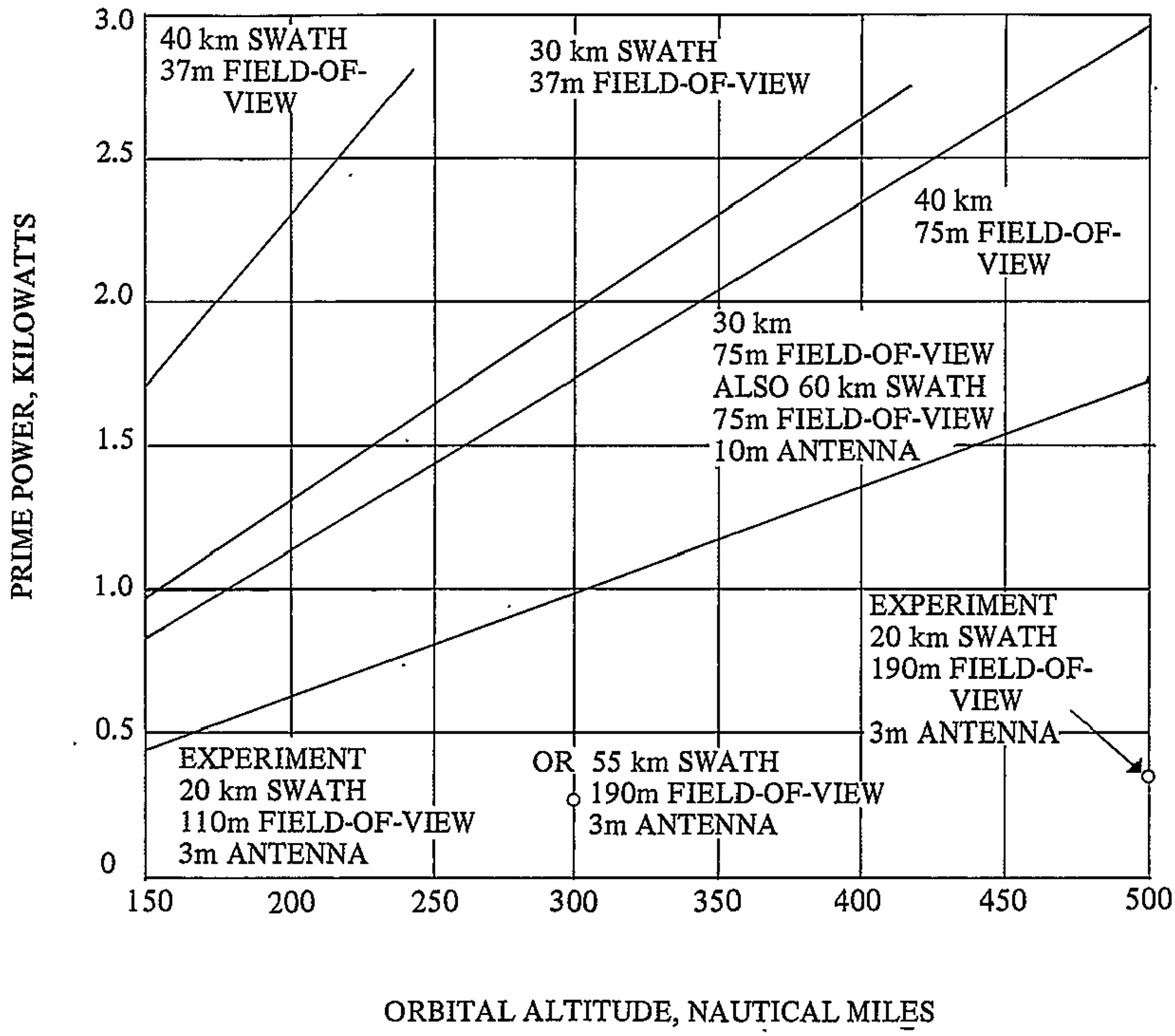


Fig. 4.5 Synthetic aperture radar (5 meter antenna except where otherwise noted) [5]

countries should be trained by the TRIAD system in data acquisition, data handling, and user application. As Katz points out, "the 'political participation benefit quotient' for the satellite comes close to zero, if it does not come in negative, but, for the aircraft operation, the benefits for foreign involvement will be 'measurable, positive, and large'."

Role of Ground-Based Sensors

A comprehensive earth resources survey program must include pertinent data collection from sensing devices which operate on ground-based platforms. These sensing devices may not be suitable for use at satellite altitudes, may be uniquely limited to gound use, or may be located in sites difficult or expensive to contact and service from the ground. It is believed that the majority of these ground-based sensors would supply observational data to the survey program through direct means such as land-line connection or periodic visit. Some of them, however, may yield their data to the system more economically and efficiently through satellite relay.

The decisions concerning the use of sun-synchronous satellites for data relay from ground-based sensors should be based on relative costs of alternate methods and the observational time requirements. Many of the ground-based sensors whose data are to be relayed by satellite would be rather remotely located. It is likely then that the sun-synchronous satellite receiving the data for relay may not be in view of a ground receiving station. Some on-board storage capacity or capability of further relay of the data to another satellite would be required. Since the near-term outlook for reliable on-board storage capacity is not good, the previously discussed system of geosynchronous data relay satellites should be considered.

At the present time, ground-based sensors are supplying some of the data needs of all the earth resource disciplines. Here, the definition of ground-based sensor is restricted to unmanned devices which automatically transmit data to some collection point or else record the observational data for pickup by infrequent visits. Many other procedures and methods are used by researchers and surveyors in the collection of data relating to earth resources. In fact, the agencies who would be principal users of data from an earth resources survey satellite program already support very large research efforts. The information to be derived from a satellite program would be a relatively small part of the present data production efforts of the research division of these agencies. The satellite data would be, however, an essential portion of the overall data inventory. Their availability would enable the users to develop more sophisticated systems models upon which improved management decision could be based.

Remotely sensed data from satellites suffer one severe deficiency. There must be related information by which the remotely sensed data may be calibrated and interpreted in terms of resource parameters. This information, known as "gound truth," may be required to be collected concurrently with the remotely sensed data to which it relates. For example, thermal IR sensors may require some calibration by means of temperature measurements on the ground. Thus, data relayed by satellite from ground-based sensors may be essential to the interpretation of the remotely sensed data.

Ground-based sensors whose data may be relayed by satellite can supply earth resource information for a wide variety of disciplines. Precipitation, stream flow, water level in lakes, and snow depth are data that would contribute to hydrology. Sea temperature, salinity, wind speed and direction, and tide and current information could all be acquired from sensors on buoys and shore. Similar lists of useful data could be made for geology, agriculture, and other sciences which could best be collected by ground-based sensors via satellite relay.

Communication System

The study of the communication system has led to the proposal of a number of communication links to satisfy the needs of the TRIAD data system. Table 4.5 presents a summary of the required communications traffic and Fig. 4.6 illustrates the TRIAD communication system.

TABLE 4.4

Summary of Cummunications Traffic

Wideband data links	GDCS to SSS	SSS to GSS	CDAS to SSS	SSS to CDAS	CDAS to GSS	GSS to CDAS	NAVCO to GSS	GSS to NAVC	MET to GSS	GSS to SSS
TRIAD	x	x	x			x				
Navigation						x	x	x		
Meteorological						x			x	
Telemetry		x	x	x	x	x	x	x		x
Attitude		x		x	x	x	x			
Tracking		x	x	x	x	x	x	x		x
Command		x	x	x	x	x	x	x		x

NOTE: Tracking and command for MET is not included in this system as it is presently conceived. It would be advantageous to merge this effort, if possible.

Legend:
GSS - Geosynchronous Relay Satellite
SSS - Sun-Synchronous, Polar Earth Resources Satellite
MET - Meteorological Satellite
CDAS - Control and Data Acquisition Station
GDCS - Ground Data Collection System
NAVCO - Navigation Communications System

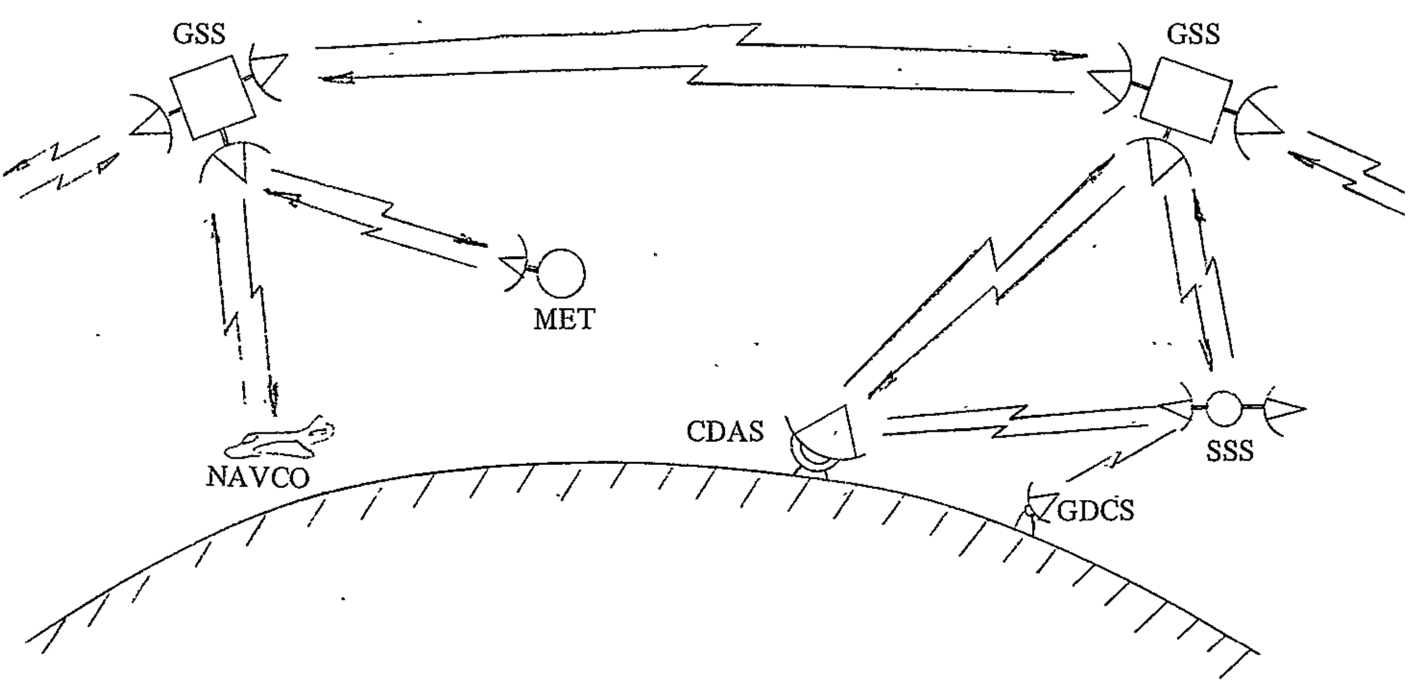


Fig. 4.6 Illustrating the TRIAD communication system

One of the major problems to be solved in the communication system is the allocation of frequencies for the TRIAD system. The available frequencies are limited, and careful consideration of the frequencies must be given to each of the subsystems of TRIAD.

The frequençies for the meteorological portion of the systems have been previously allocated. However, for the navigational communication system and the TRIAD system, some additional study should be made. For the navigational system, the existing band at 1540 to 1660 MHz (L-band) appears to be a good choice [12]. According to some sources [13, 14], certain frequency allocations are available that might be readily adopted for use by the TRIAD system, including bands in the 5, 8, 15, 31, 34, and 35 GHz ranges.

The following paragraphs discuss the general operation of the TRIAD system and specific details are given on the operation of TRIAD communication for each subsystem. The navigation communications system (NAVCO) and the meteorological data system (MET) are not a direct part of the TRIAD system. However, it is proposed that the satellite stations that are established should and could serve all of these functions.

It has been previously suggested that six high-altitude geosynchronous satellites be used for the purpose of data relay. Three of these would handle the meteorological information that is presently handled by the ESSA system. This would not eliminate the ESSA system, but rather would aid ESSA in its data relay, and would feed the necessary meteorological data into the TRIAD system. The other three GSS would collect data from the TRIAD system and assist in relay of meteorological data. All of the six GSS would be involved in the NAVCO system, allowing coverage of the earth with backup capability if any one of the GSS should fail.

The sun-synchronous satellite system (SSS) is composed of satellites with equipment as previously described to collect data for use in the TRIAD program. The SSS would communicate with the GSS and the information retrieval and location system (IRLS) containing ground data collection stations (GDCS). The control, tracking, and command of the TRIAD system, along with the data collection, is based in the command and data acquisition stations (CDAS). The discussion of the communications subsystems which follows begins with the IRLS and ground stations and traces through the direction of TRIAD data flow.

Information Retrieval and Location System (IRLS) The IRLS will consist of the GDCS described in the next section, data relay channels from the SSS to the GSS relay system, and a final relay channel to the ground-based data receiving and tracking station.

Transmission from all GDCS to the SSS from any elevation angle above 20° is proposed. This proposal results in a large ground coverage area radius of about 900 n.m. The 20° elevation angle limits the antenna angles so that higher gain is achieved, and it also avoids terrain obstruction near the horizon.

Other problems arise, however, such as two GDCS's transmitting at the same time which results in interference. It is proposed that multiple carriers be used, working into a single SSS receiver. The purpose of this is to reduce the probability of intereference and also to increase the number of GDCS that the IRLS is capable of handling.

It is further proposed that the TRIAD satellite contain a circulating memory and decision capability for the purpose of screening interference and receiving signals whose parity does not check. The data would behn be transmitted to the GSS relay system. The IRLS data should be formatted to contain the following essentials: parity bits for each 7-bit data sample, synchronizing bits, beginning and ending Barker Codes, and the platform address code.

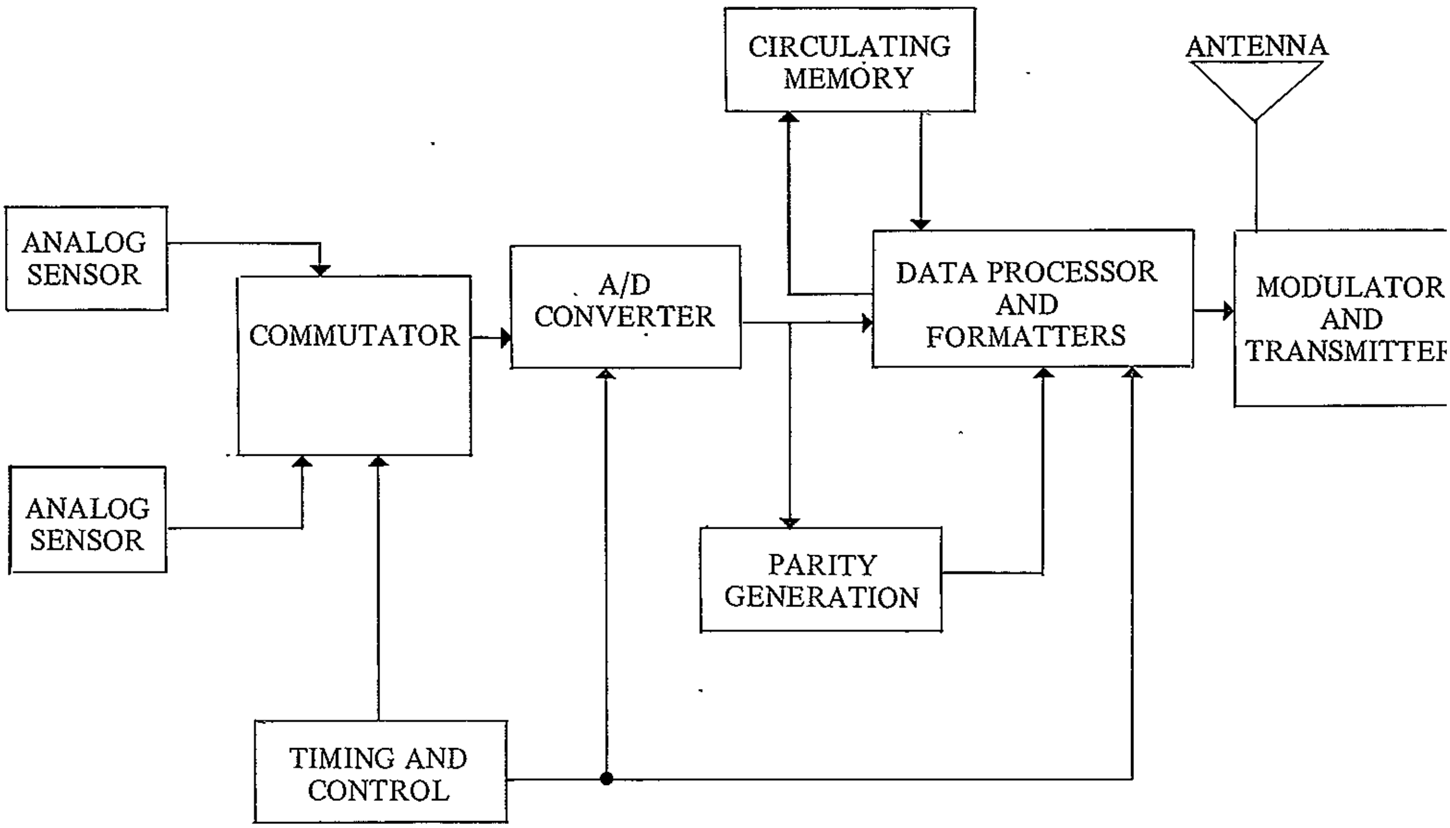


Fig. 4.7 Block diagram for a ground data collection station

The following sections describe the GDCS and the SSS in greater detail:

Ground Data Collection Stations (GDCS) GDCS would collect data from a variety of in situ sensors, process, format and store the data, and transmit the data to a TRIAD satellite. The SSS acts as a relay link to the GSS relay system.

The equipment for the GDCS should be made as simple and as inexpensive as possible, since in the future literally thousands of stations would be involved in the system.

A suggested GDCS is shown in Fig. 4.7. Since it is essential to have a simple and inexpensive station, a one-way GDCS-to-TRIAD spacecraft link is proposed. The GDCS would transmit to the sapcecraft at those periodic intervals when the TRIAD satellite was in sight.

SSS Communication Links The primary function of the SSS is to collect remote sensing data for the TRIAD system. The data, which would be wide-band, would be modulated and transmitted in real time to a GSS relay satellite. As the SSS orbit the earth, they would always be in contact with one of the GSS relay satellites for data transmission.

A control link with GSS is proposed for backup. The tracking, command, and control links between SSS and GSS would be used primarily when problems arise with the CDAS/SSS up- and down-links. A block diagram illustrating the SSS communications system is shown in Fig. 4.8. In addition to the data gathered by the SSS, the data system would receive the data transmitted by any of the large number of GDCS. The data would be received in a format such as that described in the previous section dealing with the overall IRLS data system. The data would be checked as it is received in a format such as that described in the previous section dealing with the overall IRLS data system. The data would be checked as it is received to determine if there is interference, and if the data has been received correctly. In addition, a check would be made to see if this station has been received successfully on this or the previous pass. If it has not, it would be moved from temporary memory to the telemetry subsystem. The station address code would be saved until one additional pass of the satellite is made and then erased.

To accommodate the large numbers of GDCS that would eventually be required, multichannel communication should be provided for this system. This would reduce the probability of interference and also allow a greater number of GDCS in the IRLS. A block diagram of the SSS data processing system for GDCS telemetry is shown in Fig. 4.9.

GSS Communication Links The proposed GSS has been conceived as a data relay, collection, and control satellite system. It is proposed that at least two GSS be in communication with the CDAS on the ground to provide uninterrupted relay of data and control information. This then conceivably dictates two or more ground stations to provide adequate facilities for ground support and backup.

The major functions of this system are enumerated:

1. (a) Three GSS provide data, telemetry, and command control up- and down-links for SSS.

   (b) Three GSS provide data up-links from MET.

2. Two or more GSS provide data, telemetry, and command control up- and down-links for CDAS. (It is felt that two CDAS stations would be necessary.)

3. All six GSS provide navigation and traffic control network for air and surface vehicles. In addition, a search and rescue network is proposed for the NAVCO system.

4. Wideband data, telemetry, command, and control links from each GSS to the next to complete the data relay network.

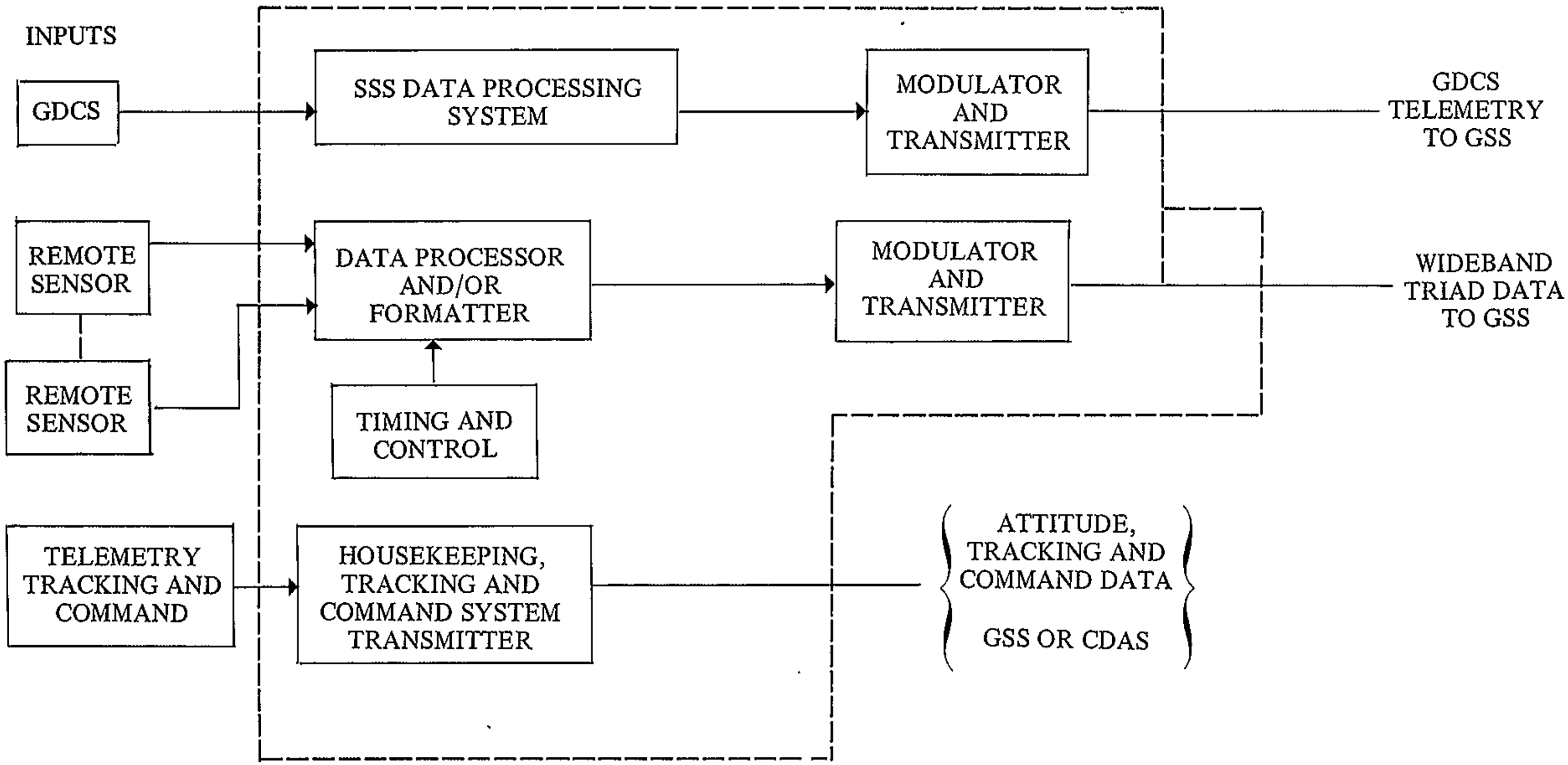


Fig. 4.8 Block diagram of the SSS comunication system

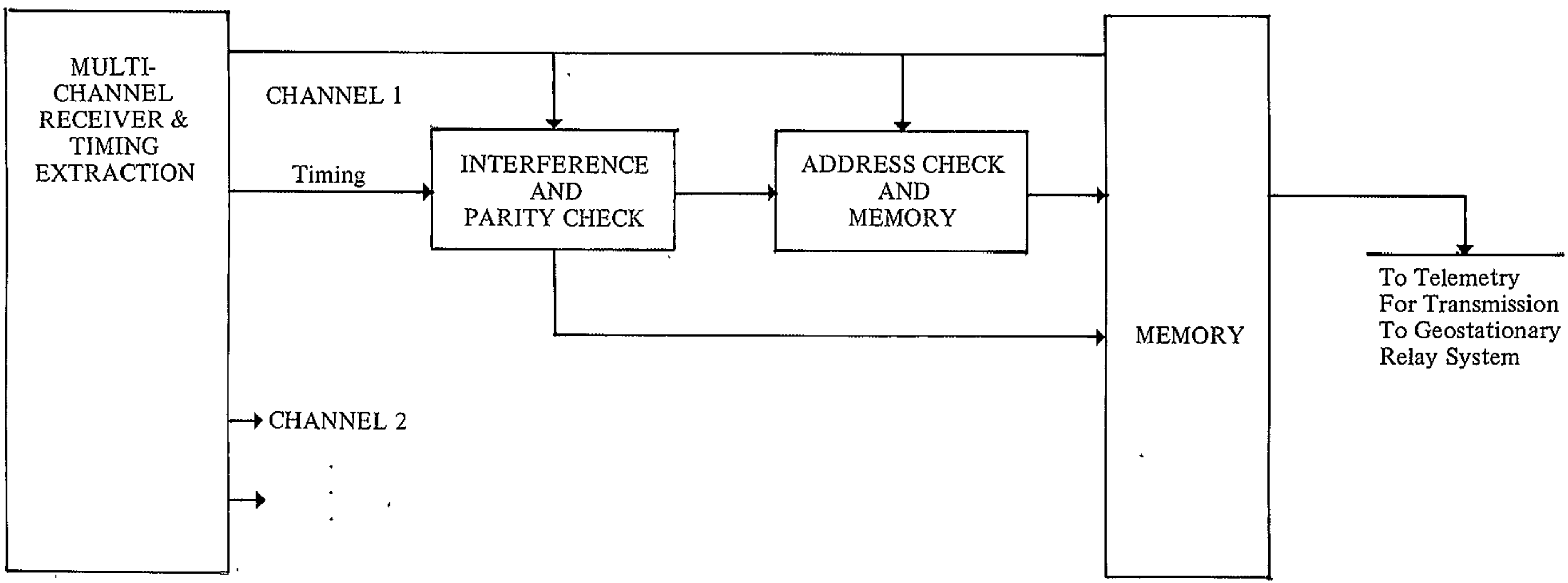


Fig. 4.9 SSS data processing system for GDCS telemetry

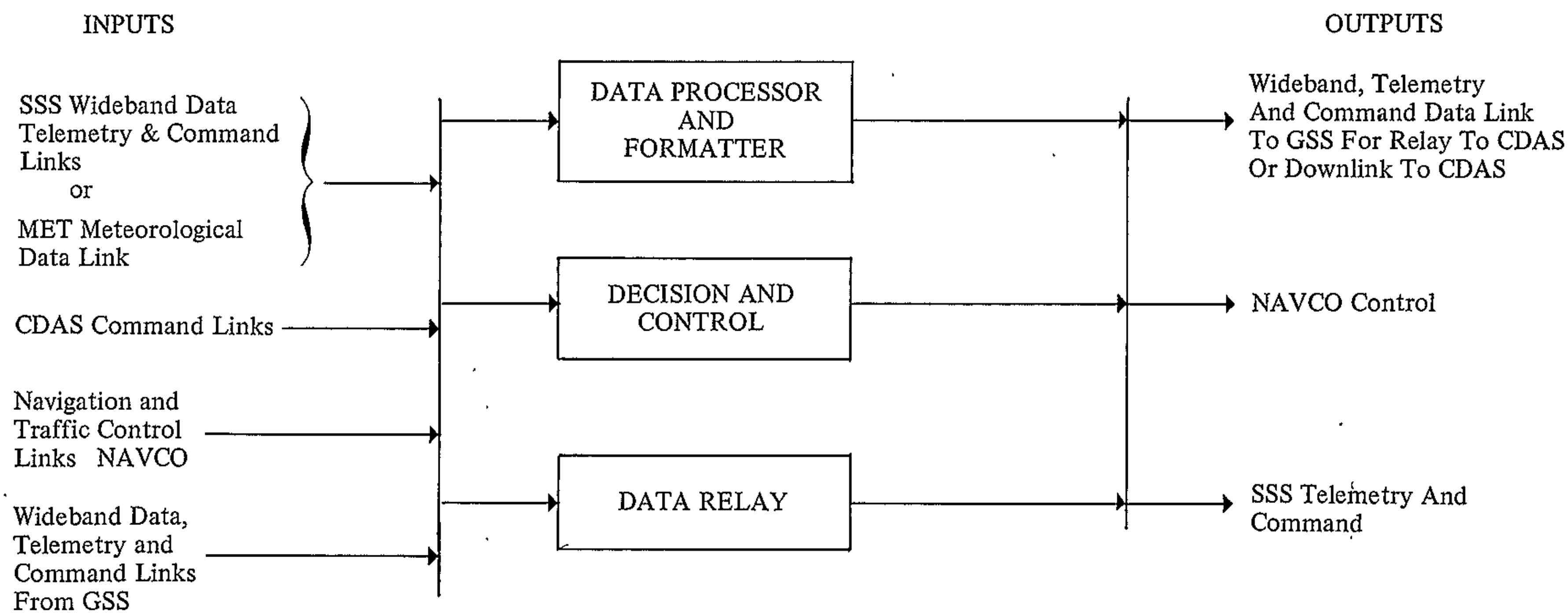


Fig. 4.10 Block diagram of the GSS communication system

The GSS would provide, as is required by various data, some processing and formatting. It would provide equipment for decision making and control of functions associated with NAVCO, MET, and the TRIAD system. It would also provide, as shown in Fig. 4.10, a system to relay data to another GSS or to the CDAS, depending on the type of data and need.

This description of the TRIAD communication system presents the preliminary design concept and has not given attention to many detailed problems that are associated with its implementation. However, in developing this concept, the problems of frequency allocation, transmitting power, antenna characteristics, computing capability and memory hardware, recorders, bandwidth, data rates, and associated problems have been studied. It is believed that the overall concept presented here is feasible with the space technology presently developed and being tested on ATS F&G [15]. The implementation of this TRIAD data communication system would accomplish the objectives set forth in Chap. 3.

Instrument and Electronic Redundancy Before any redundant instruments or components can be selected, a thorough reliability study must be performed on each component of the system. This would include a statistical model of the data acquisition and an analysis of the individual and overall duty cycles of the spacecraft and its components.

The major criteria for redundancy would be based upon the necessity of the component for satisfying the mission objectives. Any component which would render the satellite useless would automatically require redundancy. The remaining components would be analyzed for failure and their effect on other components. This analysis, in combination with the reliability analysis, would dictate a priority for redundancy for each component.

4.3 THE DATA HANDLING SYSTEM

Introduction

The total data handling system is shown in Fig. 4.11. The system is divided into three task areas: Collection, Processing and Storage, and Distribution. Over-all control of these task areas comes from an administrative control center.

Collection

The information which would feed into a comprehensive earth resources survey system would come from a variety of sources. (See Fig. 4.11a) Some of the information would be collected and processed by the system on a near real time basis. This kind of information would include data from satellite-borne remote sensors, data from satellite tracking devices, and data from ground-based sensors relayed by satellite telemetry. Other information used in the survey program would originate from air-borne sensors on aircraft and balloons. Still other information essential to the survey program would be derived from observations on land and sea.

All of these data, from whatever provenance, could be integrated in the Data Handling System to provide the users with maps, images, photos, or other forms of correlated and calibrated data. Some of these data would be received directly from the Collection Centers and some from other data collection systems. Control over the flow of all these varied kinds of data would be a function of the administrative control center, which is in turn controlled by ERSA.

The Collection Centers would be concerned with receiving, reviewing, and relaying information from satellites. Satellite control commands would be transmitted through these stations from the administrative control center. These stations would do a limited amount of data processing, mostly emergency quick-look monitoring and preliminary quality control. Data would be routed directly to the administrative control center when emergency action is indicated. In general., if data was of poor quality it would be discarded. Prior to "quick-look" the tracking, attitude, time, orbit and other data related to position would be annotated to the sensor data. The bulk of the data from both on-board sensors and data relayed from ground stations would be duplicated with copies transmitted to the Handling Center. The Collection Center would retain the original data in temporary storage pending receipt of a copy by the Handling Center.

The first group of processes would constitute Secondary Processing. Examples of types of processing amenable to automatic machines include: rectification, distortion removal, scaling, enhancement, noise removal [16]. Also some signature analysis processing might be possible by 1975.

Special Processing would be responsible for those processes mentioned in group (2) above. Generally, a request for this type of processing would come from the user through the Service Center and the Working Data Bank.

The Working Data Bank is envisioned as a file of information which could be readily disseminated to the user. The data would be stored in the form of digital or analog tapes, hard-copy photographs, literature, and catalogs. The Working Data Bank would receive the requests from and transmit the data to the Service Center. The Working Data Bank would be the direct data link between Secondary Processing or the Permanent Data Bank and the Reproduction and Interpretation section of the Service Center. The Working Data Bank would be indirectly linked to the Administrative Control Center through the administrative office of the Handling Center. Data would be maintained in the Working Data Bank as long as there was a demand. If it was necessary for data currently in the Working Data Bank to be reprocessed, the data would be returned to Secondary Processing.

The major portion of the data forwarded to the users would be via the Service Center by mail, but provisions for rapid transmission would have to be available and the Working Data Bank would link with the Rapid Transmission Room of the Service Center to expedite data flow.

Research and Development would be concerned with improving aspects of both the hardware and software in the Data Handling System. The main aim would be to increase the automation of the Data Handling System.

The specific goals of this section of the organization would be: (1) to increase efficiency of the operation, (2) to develop new methods to permit a user to better realize the potential of the system, (3) to ascertain new applications for the system and (4) to develop new equipment and facilities.

Distribution

The subsystem for handling of user requests and distribution of data to users is shown schematically in Fig. 4.11c.

It is assumed that the Handling Center would supply a large volume of data to a small number of users. Because of the large volume of data to be distributed to the users, automatic data processing would be used extensively.

In order to describe the subsystem, a user request for data is traced through the system. The basic format of the request for data would be a form printed on an electronic data processing card. The user would fill in the information shown in Table 4.6. Most requests would be received by mail or courier although provision for telephone and teletype requests would be provided. After receipt of the request, the requested information would be punched on the electronic data processing card. Standing orders would be processed automatically at specified intervals. Orders to be expedited would be routed through special channels. Then job requests would be interpreted by a catalog librarian. Internal indexing specifications needed for retrieval and acquisition of data would be added to the job card. The catalog librarian would determine whether the data requested is presently stored, must be acquired, or is a combination of the two.

TABLE 4.5

Information to be Contained in the Request

a) user identification
b) type of request
   1) one time only
   2) new request for standing order
   3) revision of request for standing order
c) geographic area of coverage
d) date(s) of acquisition
e) processing required and output format
f) specific designation of data required (IR, radar imagery, etc.)
g) date output desired
h) minimum acceptable data quality (max. cloud cover permitted, etc.)
i) index number if known

The job request would then pass to a routing and scheduling area where the job would be added to the data acquisition and/or retreival schedule and to processing and transmission schedules. Priorities would be determined by ERSA. After the job request had been entered on appropriate schedules, control cards and other internal routing, processing, and billing instruction would be generated. These instructions would then be routed to the Working Data Bank and the processing functions as appropriate.

Data received from acquisition, storage and processing for transmission to users would be in the form of magnetic tapes, films and prints, and print-out sheets from data processing equipment. Those which were to be mailed or delivered by couriers to the user would be packed, labeled, weighed, stamped and dispatched from the shipping room. A data transmission facility might be used to transmit data to other users over telephone lines. The data would be transmitted from magnetic tapes or on-line form processing equipment in the Handling Center. At the user facility, data would be received by teletype station or specialized user hardware.

A Possible TRIAD Data System

The data system would be capable of collecting, processing and disseminating the data received from the **in situ** ground sensors, the multispectral scanner (the number of channels required would depend on pattern recognition research and development), and the four return-beam vidicon cameras. The two operational earth resource orbiting satellites would be in a 500 nautical mile sun-synchronous orbit. The return-beam vidicon cameras would have 6000 TV lines capable of 100 to 300 feet resolution. This TV resolution would require a bandwidth of approximately 4 MHz and the multispectral scanner would have a bandwidth of 4-6 MHz depending upon the exact number of channels. The bandwidth requirements for the **in situ** ground sensors are minimal and would not be a problem.

The proposed data collection system is shown in Fig. 4.12 and is based upon certain research and development being performed in multispectral signature identification. Selective data acquisition is made possible by using a TV monitor coupled with a pattern recognition system. The multispectral scanner would continuously transmit data to a computer on the ground. The computer would have the known user signatures programmed into the memory so the multispectral scanner data could be correlated with the known signatures. The computer would be able to classify these areas and hence enable the operator to be selective in the data that was kept and sent on for further processing. The multispectral scanner would sweep slightly ahead of the TV cameras so the computer would have classified the scene that is currently in the TV cameras' field of view. All of the data from the TV cameras and multispectral scanner would

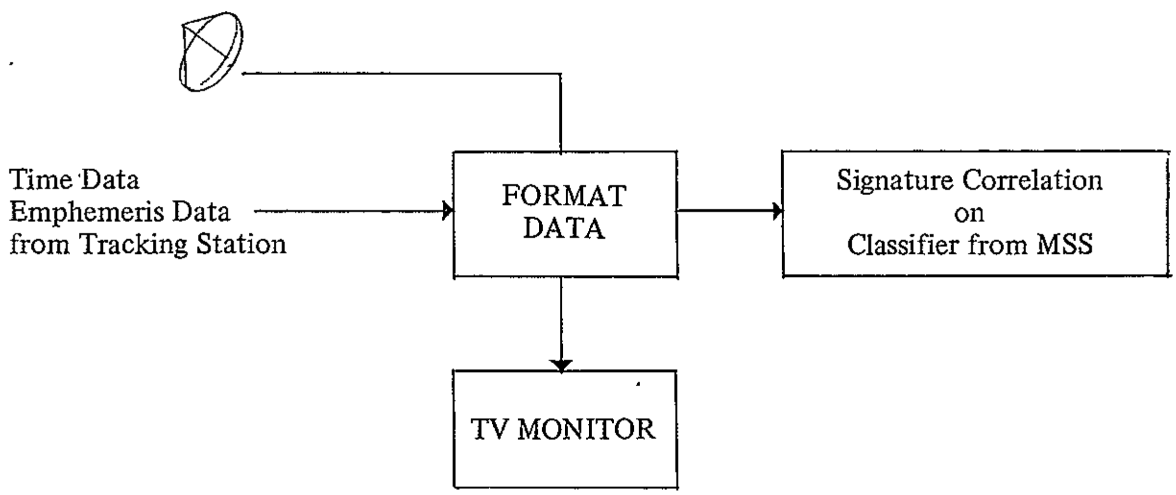


Fig. 4.12 A proposed data collection system

be recorded on tape as it is collected but only those tapes that exhibit features specified by the users would be saved and sent to the processing center. Cloud cover and quick-look phenomena would be monitored by the system on a continuous real time basis.

Two ground data collection centers would receive the data. The redundancy of two data collection sites coupled with two geosynchronous satellites capable of dumping to either station data from each satellite is desirable. The tapes from the Collection Center would be shipped to the Handling Center. The Service Center would be located with the Handling Center and near the intended users.

4.4 EARTH RESOURCES SURVEY ADMINISTRATION On the basis of the rationale of Section 3.3, an outline of the organizational structure recommended can be synthesized as shown in Fig. 4.13. Fig. 4.14 illustrates how the operational system would handle flow of data from sensors to users. Other details of the proposed administrative system are discussed in the following sections.

The Creation of ERSA as a New Independent Establishment

ERSA would be created as a new independent establishment in the executive branch of the United States Government. The independent establishment would have three distinct advantages over an organization formed within an existing agency. First, by operating separately from agencies which are users of earth resources data, an independent organizational structure would facilitate the transfer of the management function to an international organization. It is anticipated that the operation of ERSA would gradually grow into or become part of a self-supporting system with a large number of non-U. S. users; therefore, the transfer of management from U. S control to control by an international organization is a logical step in the development of the system. Finally, the proposed findung structure is more amenable to an independent, separately budget organization.

The ERSA organization would be a new one rather than one which utilizes an organization removed from an existing government agency. No existing organization in the government system is believed to have the wide range of activities in earth resources which would justify its use as a basis for ERSA.

Where Should the ERSA Agency Be Located

The Administration and the Data Processing and Distribution Center in ERSA would be centralized in one location. There would be considerable interaction between the two functions and it is therefore desirable that they be in close proximity. The ERSA Center would be the hub of the TRIAD program. It would receive all the data acquired by the satellite ground stations, aircraft and ground truth sources. The ERSA Center would have to be capable of dealing with the needs of all earth resources data users. The selection of the site location would therefore be contingent upon these postulated considerations.

Initially, the three largest users of data from the ERSA center are expected to be the United States Departments of Agriculture, Interior, and Commerce. Each of these user agencies could perform special processing of data supplied by the ERSA Center to extract the information pertinent to their specific areas of interests. It is very likely, after the ERSA system becomes operational, that additional potential areas for special processing would be needed and they would subsequently locate near the Center. Selection of the physical location of the Center should be made with the consideration that USDA, USDI and USDC currently have facilities located in the Washington, D. C. area. Under guidance of the UN Committee on Peaceful Uses of Outer Space a new UN data center serving the needs of foreign users should be located in the same geographic vicinity.

Transmission of data received by the satellite ground stations to the ERSA Center is assumed to present no problems for the state of the art in 1975.

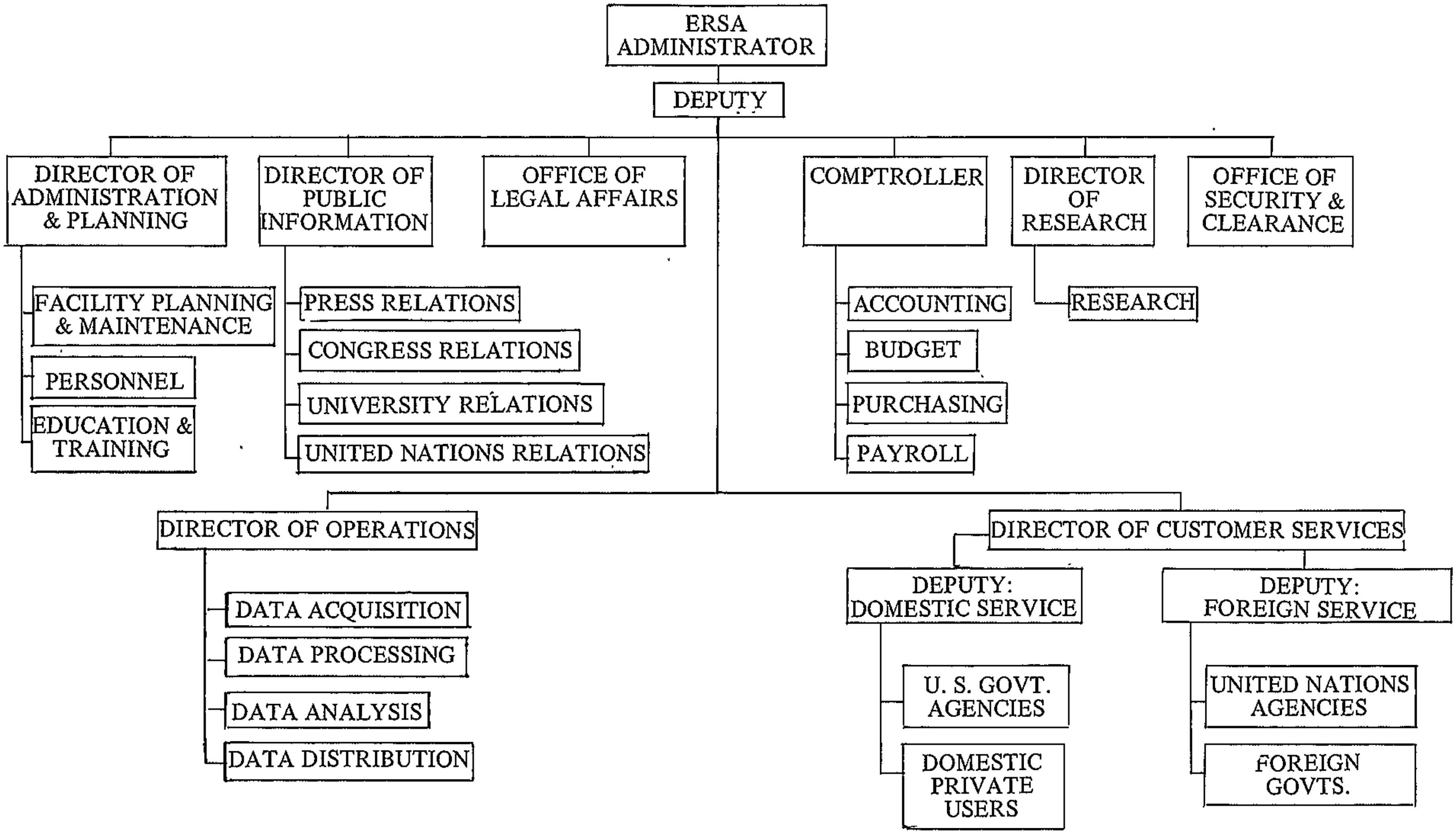


Fig. 4.13 Outline of the Earth Resources Survey Administration (ERSA)

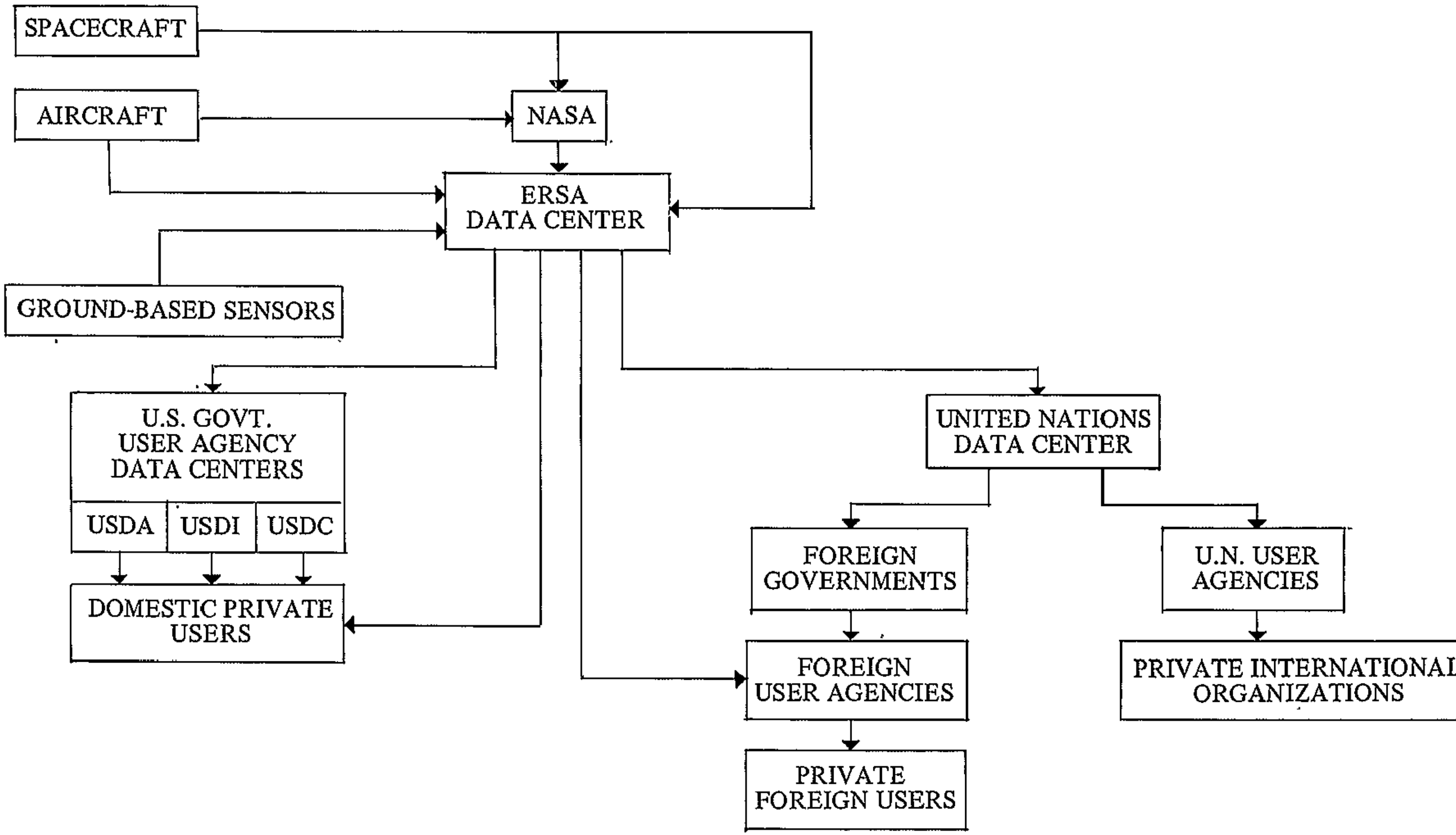


Fig. 4.14 Illustrating the flow of data from sensors to users

Explanation of Organizational Units and Functions

As shown in Fig. 4.13, ERSA provides for an Administrator and a Deputy, Directors of specific functional areas and Offices of Legal Affairs and Security and Clearance. Only the major positions are included since the specific organization of the smaller components will become more certain after various technical and financial qestions are resolved.

It should be recognized that ERSA would evolve from this initial structure as a result of customer demands, technological changes, political considerations and other influences.

The Administrator is responsible for the overall policy and direction of the program. He reports to the President of the U. S. through the Independent Offices and Establishments unit. He obtains data requirements and other information from users domestic and foreign, public and private, the UN, other government units and other interests. He directs the efforts of five Directors, a Comptroller and other specialists.

The Deputy Administrator shares the responsibilities of the Administrator as directed and acts for him in his absence.

The Director of Administration and Planning reports to the Administrator. He works closely with all other Directors to insure that short and long range planning is designed to meet their requirments and is kept current. He is responsible for layout, allocation and maintenance of facilities in cooperation with the other Directors and for procurement, induction, and training of personnel. He provides various other administrative services as assigned by the Administrator.

The Director of Public Information reports to the Administrator. He maintains contacts with the press, the Congress, Universities, the UN and all other organizations for the exchange of general information concerning ERSA. This includes press, TV, and radio releases, various prepared publications, visits by interested groups to the ERSA facilities and so forth. (It does not include specific customer contacts which are handled by the Director of Customer Services.) All publications by ERSA personnel are cleared through the Director of Public Information.

The Comptroller reports to the Administrator. He is responsible for all financial negotiations and financial records keeping as required. In coordination with the other Directors, he prepares and monitors performance to capital and operating budgets. He is responsible for payroll preparation and distribution. He gives direction to the purchasing unit which purchases all required capital and operating goods.

The Director of Research reports to the Administrator. He is responsible for systems research and development. He is responsible for research facilities, location, and layout, and design specifications and testing of research equipment. He coordinates closely with the other Directors, particularly the Directors of Operations and Customer Services, to assure that necessary research is conducted to facilitate satisfying customer requirements. He negotiates all research contracts with assistance from the legal affairs personnel and the Comptroller.

The Director of Operations reports to the Administrator. He is responsible for all phases of the data handling cycle. He directs the launching and operation of the satellites and operation of the ground stations. He is responsible for continuous liaison with ESSA, NAVOCEANO, NASA, the UN, Comsat, the Departments of Commerce, Agriculture, and Interior, and other government units such as the National Aeronautics and Space Council and the Office of Emergency Planning. He also conducts contractor liaison as required. He processes and analyzes data as required and cooperates in its distribution. He coordinates closely with the Director of Administration and Planning to assure proper planning of his operation and conformance to those plans. He coordinates closely with the Director of Customer Services to assure that the data being obtained and its processing and analysis are in accordance with customer requirements. He is responsible for physical distribution of the data in accordance with customer requirements as ascertained by the field force under the direction of the Director of Customer Services.

The Director of Customer Services reports to the Administrator. He is responsible for continuous, active liaison with users, both domestic and foreign, in order to provide accurate, current information on customer data needs. Customer Services is a field force type of operation in which the personnel contact potential customers to vigorously offer the data and services ERSA can provide and contact existing customers to insure that their requirements are being met as adequately as possible. The Director of Customer Services works in very close cooperation with the Director of Operations to insure that customer needs are reflected in day-to-day operations. Deputy Directors for Domestic and Foreign Customer Services report to the Director of Customer Services. They are responsible for activities in their respective areas.

The Office of Legal Affairs is staffed by legal specialists reporting to the Administrator. They assist in all contract negotiations, site acquisitions, copyright and property right issues, and other legal matters as required.

The Office of Security and Clearance is staffed with technical specialists responsible for liaison with Departments of Defense, Justice, State and others as required to assure that data supplied will not violate security or existing international agreements. Personnel in this office coordinate with all of the Directors, in particular Directors of Operations and Customer Services, in performance of these responsibilities.

Data Processing and Distribution, Feedback and Liaison

The design of the data processing and dissemination divisions of ERSA should be gauged to the economic, social, and political objectives of the system. It should be formulated, moreover, with reference to a realistic framework of technological, resource and budgetary constraints. In order to minimize friction, suspicion, and conflicts, care should also be taken to adapt the system to the existing set of institutions on the domestic, international, and supranational scene.

It is anticipated that, owing to budget limitations, high efficiency would be called for in the design and the operation of the system. Wherever size economies occur, e.g., at initial data processing, a centralized organization is recommended. However, where process duplication does not lead to inefficiency—probably at the secondary and special processing stages and with data interpretation—part of the work load could be contracted out to qualified firms and universities. A number of user agencies of the U. S. government and, possibly, some foreign governments might prefer to assume these tasks themselves. The decentralization of these operations also would serve to draw into the picture the service capabilities which already exist with business, institutions, and public agencies. It would thus ameliorate the absolute scarcity of certain skills and equipment which can be expected to prevail during most of the early stages of the program.

The initial data output is based largely on the recommendations by research groups and U. S. government agencies (See Section 4.1). In many instances, the usefulness of this data for public or private parties can be surmised but not established. ERSA should therefore launch a vigorous campaign to advise potential users of its activities. For this purpose publicity, market-research and marketing functions could be established as part of the system's administrative organization. Television and magazine publicity could be directed to potential public users; the interest of professional persons could be awakened or deepened by mail brochures, catalogues (or catalogue abstracts) and through the support by ERSA of research efforts leading to publication in the technical literature; finally Customer Services field representatives could personally contact prospective data users to analyze individual needs and to explain the capability of remote sensing tenchiques for filling information needs. Feedback from users might enable the Director of Customer Services to determine demand elasticities for the data to assess customer requirements. The field representatives, in particular, would be in a position to assess the effectiveness of the system at the user level and to convey requests as well as complaints and criticism to the appropriate Director. Other efforts to probe user needs should be made directly by means of formal questionnaires (carefully designed to reflect the specific interests or different user groups) and through the intermediary of other distributors of ERSA services, such as several U. S. government agencies, the United Nations, and foreign governments.

Two advisory functions would be provided by the Office of Legal Affairs. The first would be to investigate the relation or relevance of ERSA services to the legal and legislative system of the United States. Its task would be to obviate the occurrence of legal conflicts (e.g., torts concerning property or copyright claims) and to advise legislative bodies at all levels of government about the utilization of data in the conception of laws pertaining to resource management. This office would work in liaison with various federal, state, and local government departments (at the federal level, e.g., with the Departments of Justic, Commerce, Interior, and Defense, as well as the FTC and FCC) and with Congress and other domestic legislative assemblies. The second analogous function involves the area of international law and diplomacy. In this regard, the Office of Legal Affairs should work in close contact with the Department of State, the United Nations, and with foreign national or supranational governmental institutions.

Financing of Earth Resources Survey Administration

The program proposed for the financing of ERSA requires that a progressively larger share of ERSA costs of operations be borne by the data users, both domestic and foreign, as the benefits from the data to those users become established over time. Assuming an operational earth resources survey system in 1975, during the initial years of operation—perhaps between 1975 and 1980—ERSA would establish uniform charges for initially processed data to all public and private users sufficient to cover only its processing and distribution costs (variable costs) in supplying any user. All capital costs of operation: launch vehicle, sensor package, gound station equipment and administrative overhead would be provided by Congressional appropriation for ERSA. In addition, Congress would continue to support research and development activities in ERSA for the improvement of sensors, satellites, ground tracking and handling equipment, necessary to the continued progress of earth resources surveying. However, any user who requested ERSA interpretation of data would be charged the full cost of such service (capital and variable cost).

Subsequent to the formative years of ERSA operations and assuming continuing user interest in and support for data supplied by the agency, charges for data would be raised gradually until users were paying not only the variable cost of supplying them with the data but also their pro rata share of capital costs. At such time, Congress would limit its allocation of funds for ERSA to the research and development program, and to the funding of specific data acquisitions by ERSA which, for good reason, were not being supported by private firms, another unit of government or international agency.

Immediate efforts should be made to obtain foreign interest and participation in the program. To accomplish this task it first would be necessary to identify possible foreign users both public and private. For instance, how many agencies equivalent to the United States Department of Agriculture are there throughout the world? What are their names? How much do they spend to collect crop information and how accurate is the data? Answers to these and similar questions obtained about other potential international information users would help initially to clarify the extent of the foreign market and enable one to make a subjective evaluation of the value of the information to the foreign user.

Assuming that studies pinpoint potential international users, by country, of ERSA generated data, the DEputy Director of Foreign Customer Services (See ERSA organization chart) would then be in a position to know whom to contact in each country and could proceed to inform these persons of the nature and quality of the data that could be provided to them. This would hopefully be followed by negotiation of contracts between ERSA and foreign users to supply data at specified prices.

Concerns in International Acquisition and Distribution of Data

An earth resources satellite system, monitoring resources of the world, would survey and pass over international boundaries and territories having specific government control. The observation of diverse phenomena ranging from agriculture and forestry to city planning would involve remote sensing of all the land and water surfaces under the flight path of the data collecting platform. Discretion or prohibition of monitoring due to military installations, reluctance of individual governments to have information about resource location and quantity divulged, the problem of redundancy of data collection and the need to elininate insignificant data information would necessitate a stringent control of data handling, storage, and processing. Diplomatic concern over viewing the territory of sovereign states could be a problem but so far there is no evidence that this constitutes any real barrier. Currently, many foreign governments appear favorable to surveys of their domestic resources if certain precautions are tanen. However, when a resources satellite system becomes fully implemented and operational, international questions and difficulties may arise. Formal understandings and agreements should be acknowledged by the governments whose territories are surveyed. All states concerned should fully understand just what information is collected, which areas are being monitored, and what data is involved. If nations object to having land resource data information freely available and distributed to other nations, their wishes should be respected. Any nation should have the right to request that satellite sensors be turned off over its territory.

The approval of the nation concerned would be required before data obtained over that nation is distributed to outside interests. A specific contract involving data acquisition and distribution for a nation could be used only by that individual nation in question unless voluntarily released; information collected could be classified to all other parties. By providing for national classification of this data, other interested parties could not acquire the same information.

The United Nations Committee on Peaceful Uses of Outer Space is charged with the orderly conduct of space activities and supervision of data to insure, acknowledge and honor the sovereign rights and wishes of individual nations. No national data would be withheld from a participating country, no data would be collected over territories controlled by a nation objecting to data collection, and no data would be distributed without the consent of that nation concerned. Data collecting and handling should be reserved for each country at a central collection center, at individual centers in each country, or at specific centers found in only a few countries. Regardless of the collection arrangement, national jurisdiction should prevail. Governmental liaisons representing the disciplines receiving data information in each nation should be identified early. Agents representing nations would need equal authority comparable to each participating state to insure a smooth and rapid exchange of ideas, requests, and objections.

Conclusions

1) The administrative organization for an operational earth resources survey system should be located in a new independent establishment in the United States Government to be called Earth Resources Survey Administration (ERSA).

2) The capital costs of the system should be funded by Congressional appropriation initially with user paying the variable costs of ERSA data until the customer market has developed to the point where most of the costs could be recovered from prices charged to all the data users.

3) The system should be global in its acquisition and distribution of data on earth resources and would include data obtained from spacecraft, aircraft, and ground sensors but with some selectivity being exercised to (1) exclude or reduce the acquisition, processing, storage, and distribution of data of dubious value and (2) to heed explicit requests from foreign nations for the omission of their territories from the surveys.

4) NADA should probably continue in research, development and launching. Command control, tracking, and ground station acquisition of data may be handled directly by ERSA or be assigned to NASA or other contractors.

5) There should be a central reception and processing center in ERSA but more refined processing for special user needs could be handled in functional governmental user agency centers or by private domestic and foreign government centers.

6) A United Nations distribution center should be established to facilitate channeling information to non-domestic users.

7) ESSA should continue to handle meteorological data and Comsat continue with its Intelsat communications system but close relations should be established between both of them and ERSA, including the possibility that relay satellites might be launched to facilitate the acquisition and distribution of ERSA and ESSA data.

8) Both public information and customer service and feed-back should be provided for in the system's administrative structure;

9) Provision should be made for offices of legal affairs and for security and clearance;

10) Consideration in designing the administrative organization structure should be given to flexibility and adaptability to accommodate anticipated increasing foreign participation.

Evaluation of recommendations:

1. While the creation of a new government agency might cause a further increase in the federal payroll and might be opposed by those concerned with proliferation of government agencies, the new unit would have a specific area of interest, earth resources, which it can pursue without the conflict that might occur if it had a variety of different functions and it is not as apt to be overly influenced by any other agency or department of the government if it has separate status.

2. In addition, Congress might be reluctant to appropriate all of the funds required to make the initial capital investment but their provision would allow for the needed development of the system on a broad front and in a timely manner.

3. The system should be global in its acquisition and distribution of data and in its inclusion of data from different types of sources if it is going to deal comprehensively with earth resources and their use. At the same time, considerable selectivity should be exercised in the acquisition, processing, storage, and distribution of earth resource data or it will be impossible to make any effective use of the vast accumulation of data that would otherwise take place. There might be some hesitation by foreign users to associate with ERSA in its early stage because it is a part of the United States Government. Furthermore, if ground stations are located only in the United States this might cause foreign users to question the privacy of data. However, the provision for national option to limit or forbid data acquisition over any area within its jurisdiction should reassure foreign participants that their resources will not be exploited without their consent. Also, it would greatly facilitate the establishment of uniform customer charges for data to acquire and distribute that data from a central point.

4. Although it is not recommended that in an operational system NASA do many of the things with which it has been identified in the research and development period, it is assumed that in those fields where NASA has already developed special competence and experience it would be logical for it to continue to concentrate on at least some of them if it is willing to do so. ERSA should be given maximum flexibility to either operate or to contract with NASA or other contractors for ground station operation and command control.

5. The creation of data processing facilities in the user agencies as well as within ERSA could result in some duplication of facilities and increase competition for qualified personnel to do

the analysis and processing. On the other hand, processing of data fulfilling common user needs by ERSA should result in economies of scale while allowing the user agencies maximum flexibility to do more refined processing as dictated by their special requirements. User agencies would have maximum control over this critical aspect of the operation and central processing can be relieved of some of the burden of processing and storage.

6. At present, the United Nations does not have the qualified personnel or the facilities to undertake the operation of an earth resources data center. The Committee on the Peaceful Uses of Outer Space already has an extremely broad and varied assignment and the additional responsibility for directing a data center would greatly complicate the committee's functions. The creation of a new body within the United Nations would entail considerable effort and cost. However, the proposed United Nation distribution center should be valuable in servicing foreign users and it would not be necessary to engage in an extensive publicity campaign because the United Nations is so well known already. It could expand its functions as the possibility of an international administrative system was being considered.

7. ESSA might be unwilling or unable to cooperate with ERSA because of technical or political difficulties, but the proposed interface with ESSA to obtain meteorological data would avoid duplication and provide ERSA with data to correlate with the data it obtains. Maximum user satisfaction thus would be facilitated.

8. No method exists for guaranteeing that users, especially foreign nations, will accept ERSA data instead of establishing their own earth resources survey systems individually or jointly. However, the Customer Service Unit of ERSA has been designed to provide for vigorous customer contract, foreign and domestic, in an effort to expand the number of data customers. A follow-up function to keep existing customers satisfied also has been provided.

9. The recommendation for an Office of Legal Affairs and another for Security and Clearance should not require much explanation, since both legal and political security problems can be anticipated which will require close attention by trained personnel.

10. The transition from national to international administration might be hindered or even prevented by vested interests once the national organization has been created. However, the proposed administrative structure is capable of expansion, contraction, or other adjustments as required by changing circumstances.

CHAPTER V

EPILOGUE

There is no doubt that technology will contribute greatly in the attempts of man to manage and control the environment in which he lives. However, technology will only provide one part of the complex puzzle which must be pieced together if man is to survive indefinitely on this globe. History has shown mankind to be rather inept at solving problems at a local or regional level, let alone on a global scale. However, man has attacked and solved problems of monumental proportions, much to the disbelief of skeptics and professors of gloom. The real challenge facing man will be to expand his thinking to a global scale so that time becomes an ally rather than a foe. The ability of man to predict and react, in a positive way, to global changes which threaten his existence will test his determination for survival.

It is hopeless to envision, on a global basis, a society with enough common interests that perfect harmony and agreement would allow such a united action for the common cause of survival. In fact, it may even prove an impossible task to convince some nations that there is a threat to their survival in the first place. Thus it seems that the scientific community, which has been responsible for many of the rapid and drastic changes that have occurred in the past and that will occur in the future, will be faced with the enormous job of communicating with all peoples of the world and informing them of the consequences man must face if cooperation is not attained on a global basis.

Human nature is such that remedial action to any problem will occur when either the individual or group recognizes the need for action or pressure is exerted by a group which recognizes the need on those who do not recognize the need but can assist in the solution to the problem. This pressure can take many forms. It may range from brute force at one extreme to subtle economic or political coercion at the other. Thus, mankind will be faced with the overwhelming task of overcoming political and social obstacles before an objective viewpoint can be had by all concerned. Unfortunately a local area cannot control all the factors which influence its environment. Thus local solution to these complex problems becomes a necessary but not sufficient condition.

The results of the present study indicate that an earth resources survey system will eventually be of substantial value and that additional planning for an operational system is justified. But even the best operational system will provide only partial solution to many resource problems. It is clear that nations must accelerate their internal programs involving agriculture, water and air pollution, power generation, to name a few. The emphasis should be on a systems approach rather than a purely technological one. It is one thing to know the amount and extent of air pollution; it is quite another thing to effectively control it.

Research in the technological areas will branch in a number of directions as the need arises. However, hardware development will always lag basic research with the time differential between the two functions being determined by the priority assigned to each individual task (i.e., manpower and expediture). Technology has been negligent in critiquing its past developments and their ultimate benefits and detriments. Mankind cannot afford to experiment too broadly with global phenomena or with devices which exert global consequences. One of the tasks of technology will be to test all developments until their consequences are known. Unfortunately, it is often difficult to determine if the observation time was of sufficient duration or if all the interaction possibilities have been adequately explored. Thus periodic critiquing becomes a necessity.

The most pressing problem facing an operational system, other than hardware development and signature research, will be in developing man's interpretation ability and confidence in these results to the point where the resources can be adequately inventoried and managed. Some in-depth planning in this area is required in parallel with the other developments so that effective use can be made of the global data acquired by an operational system.

However, it is debatable how the developed nations should attempt to assist the underdeveloped nations. If all the nations in such an underdeveloped state were to develop at anywhere near the rate at which the United States has, the problems to be solved would be monumental and the time available for solution would be greatly shortened. In addition, it must be kept in mind that nations, regardless of size, have strong nationalistic feelings and will resist outside interference, no matter how honorable the intentions might be. As a result, subtle means of communications must be developed for informing these nations of the need for cooperation and the means by which the desired goals can be obtained using their own resources and institutions. This type of international maneuvering requires tact and diplomacy beyond current techniques and will require development.

The potential national and international problems or conflicts arising from the operation of a global earth resource survey system have only been superficially explored to date. In many cases short run benefits may mask long run consequences. It must be kept in mind that the international business community has a strong influence on the behavior of nations. Improper use of such global data without prior international agreement could cause severe disruptions in a local economy and world peace. Much thought should be directed at these areas prior to the initiation of a global data acquisition system.

The problems in administrating such a global system are quite complex and will require detailed study in the future. The administrative system recommended in this report is conditioned by the premise that any proposals that might be suggested at this time must be made within the context of reasonable probabilities which are realistically oriented to the present state-of-the-art of social, political, and economic development. Given the great disparity between nations which currently prevals and the dominant position in world affairs enjoyed by the United States and the Soviet Union, it may be some time before any serious efforts will be taken to establish an internationally administrated earth resources survey system which would be global in ownership and operation.

However, it may not be unduly optimistic to predict that if only a small proportion of all of the promised benefits of an earth resources survey system are attained during the initial operational stage of United States administration, pressures will increase for world-wide representation in management and regulation. Already, even before a national operational system has come into being, a certain amount of agreement between nations in the use of space for peaceful purposes has become necessary. Launchings are registered with the United Nations and the International Telecommunications Union assigns band frequencies to specific nations for specific purposes. With an operational system, many more regulations would be required to anticipate or settle conflicts that might arise between nations and to maintain orderly and equitable procedures for acquiring and distributing the data sought.

It is therefore not too early to try to anticipate some of the problems involved in making the transition from a national to an international system and to endeavor to suggest ways in which this might be brought about. Just as the design for an operational earth resources system which is nationally administrated must begin by exploring various alternatives, evaluating them, and finally arriving at some recommended course of action, so should the more distant prospect of an international system be investigated and plans laid well in advance so that when the time comes for taking action there will be an adequate reservoir of ideas from which to draw to assure some chance of success.

To attempt to do so here is clearly beyond the province of this report. All that is suggested is that somebody somewhere should set about this task and continue at it until a satisfactory system can be designed which will be acceptable to the majority of the members of the United Nations. That organization may have its faults but it is the best organization known to bring the peoples of the world together in cooperative action for common objectives. Perhaps with the existent United Nations Committee on the Peaceful Uses of Outer Space and the proposed United Nations earth resources data center as an introductory approach to the problem, a program could be worked out whereby each continent would be responsible for its own earth resources survey system and its own central data center, some of this data then being channeled to the United Nations Center, and with United Nations over-all supervision of the component parts of the system. Another alternative might be to have a more centralized system of operation from a single center and reverse the process just mentioned by having data distributed from headquarters to continental or other regional distribution centers. Numerous other plans are possible of course and perhaps some future systems design group may have the opportunity of working on such a project.

The problem of data handling will require high priority in the immediate future. Ground truth, calibration of instruments and pattern recognition are necessities for establishment of a reasonable confidence level in the system output. The development of statistical and selective data acquisition methods and computer analysis techniques will continue to receive large emphasis. Although the photographic format satisfies the greatest number of present anticipated users, it is not entirely clear whether or not computer generated mosaics might be superior because they would suppress unwanted information and accentuate desired information. A large priority should be placed upon the problem of educating and training the potential users in the interpretation of this data, regardless of its form.

The engineering and scientific community will be faced with solving numerous technological problems necessary for the evolvement of an operational system. These problems, however, are relatively easy to solve in comparison to the social, political, and economic ones. The scientist and engineer have the distinct advantage that their problems are well defined and do not require extensive cooperation among disciplines for their solution. However, in our rapidly changing society the technological community can no longer consider their work in such an independent light and it must develop interdisciplinary techniques so that the non-technical problems related to technological developments will receive proper attention and paralleled activity.

In conclusion, a few comments should be made concerning what this study has and has not done. The preliminary design concept presented depends upon the results of numerous technical and non-technical research projects. Until many of the issues posed in this report have received adequate attention, it is rather speculative to consider a design of an operational system. However, if and when the case for an operational system is made, it is felt that the preliminary design presented has merit for further investigation. It would be naive to gloss over the obvious technical problems involving frequency allocations, wideband communication links, relay satellite hardware, to name just a few. However, it is felt that most of these problems are of engineering nature and can be solved once the decision has been made to pursue an operational survey system. The gap between the present state-of-the art and a future operational system is quite large and will require extensive studies in both the technical and non-technical areas suggested before the policy makers will have sufficient information for making intelligent decisions. Close attention should be paid to showing how the data received can and will be used in the solution to the proposed problems. Those who proclaim needs must justify these needs by presenting convincing arguments on the non-economic as well as the economic issues relating to these needs. It is hoped that this report asks many questions which need answering, by detailed and comprehensive studies.

APPENDIX I

GLOSSARY OF SCIENTIFIC TERMS AND TECHNIQUES

A semi-technical description of some of the terms and instrumentational techniques employed in writing this report.

Absorption Spectroscopy. A general term—the measurement of the attenuation in the intensity of a signal (generally a narrow band as the term spectroscopy implies) as a result of its having traversed a medium which absorbs a portion of the signal.

The attentuation is a function of both concentration and distance. The distance is usually known, unless clouds also absorb the signal being investigated. The concentration of atmospheric constitutents vary horizontally and vertically, and one component may very well obscure another component's signal.

Vertical absorption spectroscopy will be difficult, or impossible in many cases. Satellite-to-satellite spectroscopy through a broad expanse of the atmosphere may be more practical. The latter case would be an active system. Virtually all other applications will be passive.

Active System. A system in which a signal (radio, radar, visible light, etc.) is generated by the instrument for measurement purposes.

Backscatter. A phenomenon in which radiation is scattered by its interaction with some medium. In many measurements of such scattering, only that radiation which is scattered back to a region near its origin is measured.

Bolometer. A general term for several different types of devices which measure electromagnetic radiation.

All are based upon their electrical conductivity, either applied or induced, as a function of their temperature, which in turn is a function of the radiation flux entering the device.

When exposed to radiation, pure metals, alloys or thermistors generally decrease in conductivity. Some metals when joined with a dissimilar metal (thermocouple) generate a small potential when heated.

For remote sensing, particularly for wave lengths greater than ca. 8μ the bolometer must be greatly cooled so as to reduce the dark current (natural electronic "noise") and to get to a super conducting state due to the weak flux one will be sensing. At this time, the cooling (cryogenics) is the greatest technological problem. Newer alloys are being developed which do not have such severe cooling requirements (ca. 4°K) but will operate in the 90-120°K range. Some systems which can be sufficiently cooled by radiation to deep space are in operation (Nimbus THIR system). For those sensors requiring cryogenics, their life is currently limited to about one year.

Detectors in the mid-infrared are essential to complete spectral signatures, and to observe such characteristics as temperature.

Infrared detectors are limited (or totally thwarted) in their accuracy by atmospheric particulate material, humidity, and clouds.

Bolometers can be constructed to work in the ultraviolet, visible, near-infrared (solar reflection) mid- and far-infrared (thermal).

Far-infrared (60-400μ) detectors are still highly experimental. The advantage of going to the far-infrared is that particulate material, humidity, etc., are not as critical in their interference there as compared with the 6-30μ region where most work is currently centered.

In the far-infrared another divice, the **Golay cell**, may be used. In the Golay cell, the radiation heats an enclosed chamber of gas which expands and causes one wall of the chamber (a diaphram), to which a mirror has been attached, to distend, thus deflecting a beam of light into a photomultiplier tube for measurement.

Direction Finder. An antenna or receiver which discriminates against all signals except those coming from a certain limited direction.

Electromagnetic Radiation. A general term referring to "waves" which travel at the speed of light (ca. 186,000 mi./sec.) and require no known medium to support their propogation. The whole range of electromagnetic radiation can be subdivided into various regions as a function of their frequency which in turn is the number of waves that pass a given point in one second of time. X-rays (and gamma rays) have the shortest wavelength (largest frequency). The succeeding regions, by increasing wavelength, are the ultraviolet, the very narrow visible region, the infrared (heat), followed by microwave, radar and radio waves.

Emission Spectroscopy. The study of characteristic frequencies emitted from a substance when excited by some energy source (Confer absorption spectroscopy).

Emittance. The ratio of the emitted radiant flux per unit area of sample to that of a black body radiator at the same temperature, and under the same conditions.

Giegar Counters. Gieger counters detect nuclear particles (alpha and beta). Due to the extreme attenuation of these particle streams with distance, such devices will necessarily be confined to surface sensor platforms. (Unless interested in upper atmosphere and extraterrestial counts).

They could be employed in remote areas to monitor stream pollution (old abandoned radioactive mine tailing, etc.) or fallout.

The energetic particles enter a gas chamber, ionize the gas which then is attracted to a charged central electrode. The rate of discharge of the ion particles is electronically counted. Gieger counters will detect gamma radiation, but for greater efficiency scintillometers are preferred. Special systems are required for alpha particle monitoring.

Gravimeters. These instruments measure the earth's gravity field, anomalies in which may reveal geologic structures and associated mineral and oil deposits. Gravity measurements are often correlated with magentic measurements in interpretations of subsurface geology.

Gravimeters operate variously, from a swinging pendulum housed in a shielded building on the ground to an aircraft- or satellite-borne gyro-stabilized accelerometer. Ground-level resolution required is of the order of 1 mgal. and 200-300 meters. These limits are probably within the 1975 operational state-of-the-art, although much work in this area is classified. Needs in terms of earth resources satellite survey probably would have low priority.

Data rate to the ground is not high, but computer time to interpret the data is more than equal to sensing time.

Ground-based Sensors. One of the tasks which may be economically and scientifically feasible for an earth resources satellite to perform is the relay of data from ground-based sensors. These sensors may be located in remote or inaccessible sites on land, or on buoys at sea.

The data supplied by these sensors could be "ground-truth" information useful in itself, but more important as a means of calibration for remote sensors riding on aircraft or satellite platforms. The data from these ground-based sensors more than likely will be information which cannot be obtained by remote sensors or other means.

Ground-based sensors include a variety of types. They may be simple thermometers with coupled telemetry. They may be a rather complicated sampling and chemical analysis device, measuring a number of properties of the environment in which they are located, or they may measure a wide variety of parameters such as Stream flow, water temperature, wave height, sulfur content of the air, earth vibrations, magnetic and gravity field intensities, and many others. In general, data rates are very low, and power requirements for sensors and telemetry are low.

Results of determinations made by ground-based sensors may be collected by periodic visit, by direct-wire or radio link to a ground station, or by telemetry via satellite.

INFRARED

Black and White Infrared Photography. This method is useful because water always appears black in a positive print. As a result, water distribution is easily mapped, and drainage features and shorelines are easily discernible. Some vegetation characteristics are also discernible. The cameras may be mounted on either an aircraft or a spacecraft. The film must be physically retrieved from the platforms, but the resolution is high, and the power requirements for camera operation are low. The weight requirements depend upon the amount of coverage desired. This method is satisfactory for a **limited** area since the area of coverage is proportional to the weight of the film. (To photograph just the United States once on a 1:800,000 scale would require 14 pounds of film—no overlap. For all world land areas, 280 pounds of film would be required using 9 in. x 9 in. frames. The 14-lb. figure jumps to 896 lbs. for 1:100,000 scale coverage.)

Color Infrared Photography. This method is of value because it shows significant differences in vegetation, and allows identification of species, diseases, and morphological abnormalities. This technique shows minimum variations in color and tone for each individual species of vegetation, and is therefore a very good method for signature identification. The moisture content of soils may also be discernible. The film must be physically retrieved from the platform, but the resolution is high and the power requirement is low. The weight is proportional to the amount of film used and hence the area of coverage. This method is satisfactory for a **limited** area (**vide supra**—parenthetical note).

Image Orthicon Camera for Near IR. (IO) The camera uses a sensor that operates in the 0.75 to 1.1 micron spectral band, and the tube is sensitive to illumination intensities ranging from 10^{-5} foot candles to 10^{+4} foot candles. The camera head consists of an image and shutter optical system, and an image orthicon tube, electromultiplier and circuitry. The impinging infrared photons are converted to photoelectrons which are in turn focused into a photoelectron stream which is an electronanalog of the imaged scene. The optical band from 0.75 to 1.1 microns is the band of high reflectivity of growing vegetation and is of importance to agriculture and forestry. Since water completely absorbs this wavelength, water distribution is easily discernible. The ground resolution is 500 feet at high contrast, and about 800 feet under moderate contrast. This resolution capability is for a 100-mile swath, and an image orthicon capability of 1000 TV lines. The camera head weighs 26 pounds and the opitcal system and electronics system 5 and 13 pounds, respectively. The maximum power requirement is 60 watts with a standby of 7.5 watts. The video band width for a 1000-line image orthicon camera covering a 100-mile swath, assuming a readout time per frame of 24 seconds, is 30 KHz. Readout times could be reduced to as low as 10 milliseconds with a corresponding increase in bandwidth. Note that the area of coverage is independent of the weight, but data handling problems may limit the data.

The system is a companion to the return beam vidicon (RBV) which has very limited near infrared capability.

Infrared Imagery. (vide infra—last paragraph on infrared radiometer.)

Infrared Radiometer. (IR Scanning Radiometer) A radiometer that measures the radiance of a system, in this case, in the infrared region, and with a scanning device.

A General Electric developed sensor will monitor two infrared bands. From these measurements it is possible to deduce certain geologic information about rock types, to determine water temperature, and to monitor volcanic activity and forest fires.

The General Electric device weighs 55 pounds, requires 90°K temperature, has a 12-watt standby and a 100-watt operational power requirement, and each channel has a data bandwidth 10^5 Hz. The ground resolution if 1500 feet at 500 mm.

Infrared radiometer information is easier to handle than infrared imagery (producing an image—on film or transmitted back via television)since the emissivity of the scene is variable.

Interferometer. The Barringer Correlation interferometer is able to measure the carbon monoxide and carbon dioxide content of the atmosphere. The 2.32-2.37 micron band is scanned by changing one of the two optical paths in an oscillatory manner. The actual absorption spectrum of the gas is obtained by correlating the oscillatory motion of the mirror with infrared detector output to form a characteristic interference pattern. The absorption spectrum of pure CO or CO_2 content is then determined.

The CO and CO_2 concentration can be determined over the entire globe if the interferometer is placed in a 500mm orbit. The SO_2 content may also possibly be measured.

Air pollution could be monitored with such a device and the CO sink anomaly could be studied.

The estimated weight is 50 pounds, and the volume is 1.5 cubic feet. The peak power requirement is 30 watts with an average power of 20 watts.

Data rates are estimated to be about 100 bps.

The above specific example refers to operation in the infrared spectrum. The technique is equally applicable to other regions of the spectrum, and for other substances.

Intervalometer. A clock device (or a man) that measures preset intervals of time, and then triggers some function.

K° Kelvin or Absolute Temperature. 0°K is taken as "absolute" zero. 273°K = 0°C or 32°F. 300°K = 27°C or 81°F.

Laser. A device for producing light by emission of energy stored in a molecular or atomic system when stimulated by an input signal. Of two basic types: pulsed and continuous wave.

Laser Altimeter. A device for measuring vertical distances. It emits a pulsed laser beam and monitors the time for the reflected return. At present laser altimetry is judged as inferior to radar altimetry. Maximum altitudes of 1000 km, and accuracies of 0.5 m are anticipated.

Magnetometers. These devices measure the earth's magnetic field intensity. Common types are fluxgate and proton precession. Present surveys are mostly from aircraft platforms. Information obtained is useful in interpretation of subsurface geologic features, and location of mineral resources. Synoptic data from satellite platforms would be quite useful scientifically, but of low priority in meeting immediate needs of an earth resources satellite survey. Data rate is low. Corrections must be made for natural fluctuations in magnetic field which requires a fair amount of computer time. Data is best interpreted in form of thematic maps. (Confer Gravimeter.)

Metric Camera. (Metric Photography) The recording of events on film (either singly or sequentially), together with appropriate coordinates, to form the basis for accurate measurements. (vide supra—parenthetical note under infrared.)

Microwave Radiometer. A microwave radiometer is a passive device used to measure microwave energy radiated from the object to be observed. The amount of energy radiated or emitted by an object is a function of wavelength, temperature, and composition of the object.

Presently available and being flown on NASA's aircraft program is a multi-frequency microwave radiometer operating at the following frequencies: 1.42 GHz, 10.625 GHz, 22.235/22.355 GHz and 31.4 GHz. The temperature sensitivity is less than 1°K for 1.420 GHz, 10.625 and 31.4 GHz bands, and less than 2°K for the 22.235/22.355 GHz band. The instrument range is 0°K to 500°K and the integration time is 1 second. These flights are made to a maximum of 30,000 feet.

Microwave radiometers have the following range of characteristics:

CHARACTERISTIC	TYPICAL	BEST	UNIT OF MEASURE
Sensitivity	1	0.01	Degree K, (RMS)
Integration time	1	0.001	Second
Resolution	1	0.01	Degree K
Bandwidth	0.1	200 to 0.01	Percent
Frequencies	10	0-3000	GHz
Wavelength	36	Large to 1.0	mm

Spacecraft requirements for an electronically scanned microwave radiometer (ESMR) currently being procured from Space General Corporation for Nimbus are as follows:

1. 50 pound maximum weight including antenna
2. 25 watts average power
3. Data rate of 100 bits/second
4. 100-degree scan $\pm 50°$ from nadir
5. Temperature resolution 2°K
6. Integration time 198.5 msec.
7. Dynamic range 100-338°K
8. Ground resolution 2.85° x 2.85°.

Multiband Spectral Scanner. Basically, multiband spectral scanners are electromagnetic radiation sensors that can be "tuned" to respond to wavelengths in particular bands, and image the field of view by scanning across in a perpendicular direction with respect to the carrier's direction of motion. The scan rate is so selected that the speed of the carrier causes consecutive sweeps to be contiguous. In short, the horizontal dimension of the picture would result from the optical scan, the vertical dimension from the motion of the carrier.

Scanning of a portion of the field of view can be accomplished by several methods. A design which is being developed by the Hughes Aircraft Aerospace group utilizes an oscillating mirror that images a small spot in the field of view. Hycon's scanners utilize a rotating lens turret instead of an oscillating mirror.

Splitting of the energy radiated from the field of view into spectral bands is accomplished by optics consisting of dichroic mirrors, spectral filters and prisms. The electromagnetic radiation in each selected spectral band width is measured by the most suitable detector for each spectral band. Detectors that have been used to yield the most favorable signal-to-noise ratio for 7 specific spectral bands are as follows:

Band ( )	Detector
0.50 to 0.60	Photomultiplier tube (S-20) (uncooled)
0.60 to 0.70	Photomultiplier tube (S-20) (uncooled)
0.70 to 0.80	Photomultiplier tube (S-20) (uncooled)
0.80 to 1.20	Silicon avalanching detector (uncooled)
1.55 to 1.75	Indium arsenide detector (195°K)
2.20 to 2.40	Indium antimonide detector (90°K)
10.50 to 12.50	Mercury cadmium telluride detector (90°K)

The state of the art does not limit the development of only a seven-channel spectral scanner. One study has shown that the spectral region 0.3 - 2.5 can be divided into as many as 30 channels. Each channel had a signal-to-noise ratio that permitted detection of changes in reflectance of less than 1%. The cooling requirements for the longer wavelength detectors results in a more complicated, heavier, larger and greater power consuming device than a scanner that utilizes only visible wavelengths and the near IR band. Probably, for these reasons, a four-channel spectral scanner, operating in these lower wavelengths, was selected to be part of the payload for ERTS A and B. The potential high resolution visible and near IR data will satisfy a great many earth resource user requirements in a wide range of disciplines.

There are many possible methods that would utilize combinations of wavelength bands to classify multispectral response patterns obtained by multiband spectral scanners. Output could be in terms of total area of a given material (acres of wheat) or the result could be in the form of characters printed directly on a map. Imagery in color or black and white could readily be extracted from the data. There is no registration problem for extracting spectral information since the entrance slit of the multichannel spectrometer is the scanning aperture. The detectors are stable, linear, and have to be calibrated periodically by observation of sources of known radiance.

Space, weight and power requirement of a multiband spectral scanner are dependent upon the specifications of the number of wavelength bands, the spatial resolution, and the amount of data processing conducted prior to storage or transmission. Typical sensor spacecraft interface requirements for three devices are as follows:

Number of Channels	Estimated Weight	Estimated Resolution	Power Consumption	Power
7	125 lbs.	200 ft.	20-70 watts (scanner & detection only)	---
5	100 lbs.	1 mrad.	15 watts	2.7 ft.^{3}
4	78 lbs.	200 ft.	45-65 watts (includes processor)	---

A line-scanner sensor has several disadvantages over other camera systems. Since the scene is scanned line by line, all elements in the scene are not imaged simultaneously but sequentially. Therefore, any variations in the carrier's attitude must be known at all times in order to combine the scanned points into a contiguous image. Another limitation is that fewer detectors are present as compared with photographic film which has millions of detectors per square inch of film. The sensor has limitations in spectral and spatial resolution determined by considerations of size of optics, number of detectors, and signal-to-noise requirements.

Multispectral. (See Spectroscopy.)

Passive System. A system in which only naturally occurring signals, or signals generated by other stations, are measured.

Panchromatic Photography. Photography which uses a film sensitive to all wavelengths in the visible spectrum. (vide supra—parenthetical note under infrared.)

Photomultiplier Tube of Electron Multiplier Tube. Tubes which amplify signals (light or electron) about one hundred thousand times.

Point Scanner. A technique whereby only a narrow image (a "point") is deposited on an imager (or film) by having the film move at a constant speed through the camera, and a multifaceted rotating mirror reflects a narrow beam of light across the film. (Or by some similar operation.) (vide supra—last paragraph under Multiband Spectral Scanners.)

Polarimeters. A device which measures the extent to which electromagnetic radiation, emitted on one place, has been rotated due to the influence of some medium through which the radiation has passed (or acted upon by some surface).

The technique is widely exploited in the visible portion of the spectrum, and has been used for celestial observations, as a passive system. For remote resource observations it is quite useful in radar systems for greater clarity of detail, and for spectral signatures (an active system).

Prefixes.

giga—(G)	one-billion
mega—(M)	one-million
kilo—(K)	one-thousand
deca—(D)	ten
deci—(d)	one-tenth
centi—	one-hundredth
milli—(m)	one-thousandth
micro—	one-millionth
nano—	one-billionth
pico—	one-thousandth of one-billionth
femto—	one-millionth of one-billionth

Radar Altimetry. Radar altimeters have long been used to determine the locations or altitudes of aircraft with respect to the ground below. The use of altimetry on spacecraft suggests the possibility of profiling the ground. The general application of orbital altimetry will be to provide data for improved orbit calculation, and with the orbit as a reference baseline, reconstruction of the size and shape of the planet. From this, altitude control networks based on the revised planetary figure may be established, and contour maps prepared. In addition, altimetry will serve to provide nadir elevation and vertical data for scaling and contour relation of concurrently obtained photographs.

The radar altimeter has never been flown on aircraft, but has been selected for GEOS-G to be flown in late 1970. The objective in the geosciences is to improve the accuracy of the base-line and ranging measurements from the present ±10 meter region to ±1 meter or better. This is currently being approached with C-band radar measurements to about 2 to 4 meters, but with continued improvements a ±1 meter accuracy might be possible by 1975.

A data rate of 4,000 bps., weight of 50 to 100 pounds, and 80-100 watts average power are estimated.

Radar Imagery. Radar imagery is a record of the magnitude and the terrain element location information contained in the radar return. Imagery presents the optimum information content of radar return.

The image record of the terrain return is affected by the frequency, angle of incidence, and polarization of the radar signal. For example, if the terrain being imaged is covered by vegetation, a K-band (35GHz) signal will record vegetation, while a P-band (0.4GHz) signal will penetrate vegetation and record a combination of vegetationand soil surface. In general then, each frequency band represents a potential source of unique data.

The angle of incidence of the incident wave will affect the image because of radar shadowing on the backside of illuminated objects. The extent of this shadow indicated height, and is useful in emphasizing linear earth features.

The polarization of the radar signal affects the image by emphasizing those terrain features that have favored orientations with respect to the radar.

There are a number of applications of airborne or spacecraft radar, and the particular application will determine the frequency, polarization and operational system. Airborne side-looking radar presently being flown by NASA transits at 16.5 GHz at 10,000 to 30,000 feet. The power requirements are about 3 KW, and the antenna dimensions are 51 in. by 12 in. by 4 in. Coverage is for a 10mm swath from aircraft.

An orbital radar imaging system proposed would be a synthetic-aperture antenna system. The system would operate at 8 GHz, have a spatial resolution of 40 nm, weight 150 to 700 pounds, and have a 400-watt power requirement. This system would have a 5 to 8-pound film package for the images (for the U. S.), (vide supra—parenthetical note under Infrared). Film is not required, i.e., the image could be transmitted by television.

Radar Scatterometer. A radar scatterometer measures radar backscattering cross-section per unit surface area versus angle of incidence of various type of earth terrain. The magnitude of the surface area as a function of the angle of incidence can be determined for angles of incidence of approximately +5° to +60° from nadir by recording Doppler frequency and echo power density, and relating them to the angle of radiation. Data is obtained at all angles of incidence simultaneously by recording the echo signal from the terrain in conjunction with knowledge of platform velocity and altitude.

By use of different frequencies, various parameters or terrain signatures can be obtained from scatterometer data. High frequencies on the order of 13.3 GHz measure surface roughness. The lower frequencies, 1.6 GHz, will penetrate the surfaces and measure soil moisture.

The high frequency system, presently available, operates at 13.3 GHz with a resolution of 53 feet at 1000 feet altitude, a power requirement of 135 watts, and a total weight of approximately 74 pounds. The low frequency unit operates at 1.6 GHz, and has a resolution of 158 feet at 1000 feet altitude. The power requirement of this unit is approximately 65 watts and it weighs 50-75 pounds.

The aircraft versions of the radar scatterometer are currently being tested on NASA's flight tests. At present a satellite spacecraft design is not known to exist. It is likely, however, that such an instrument could be designed to satisfy weight, power, and resolution requirements of the satellite system.

Radiance. A measure of the intrinsic radiant intensity emitted by a radiator in a given direction.

Return Beam Vidicon Cameras. The return beam vidicon (RBV) is a magnetically focused imaging device. It operates as a vidicon in that the photoconductor charge pattern is produced by light, and the electrical return beam is a result of the interaction of the charge pattern and a scanning beam.

In order to use the RBV as a multispectral device, it is necessary to use a camera and filter for each band desired. The size of the imaging rectangle for a 2-inch RBV is 0.9 inch by 0.9 inch. This RBV has a potential of 5000 TV lines, but it is proposed to scan with a 4000 TV line raster. To image 100 statute miles from 500 nautical miles requires a focal length of 5 inches. F 1 or F 1.2 optics would be necessary to meet the diffraction imposed requirements.

The relative response is greater than 20 percent from 0.48 to 0.73 microns. Selection of one, two, or three bands from this region will be achieved by the proper selection of individual spectral filters for each of the cameras.

It is estimated, that with the proposed optics, and based on the resolution capability of 4000 TV lines, that the RBV will produce ground resolution of 125 feet at 100 percent contrast, and 200 to 250 feet at maximum earth scene contrast of 25 percent over a 100 statute mile swath from a 500mm orbital altitude (theoretical resolutions). (Probably will achieve 400 ft. resolutions.)

Considering a 3 camera RBV package, the weight will be approximately 100 pounds including optics. The average power requirement during camera operation will be in the range of 150 to 225 watts. One or two camera packages would be proportionately lower.

For a trispectral sensor package as described above, the required video bandwidth is about 2.5 MHz if a 5-second readout time for each camera is assumed. The video bandwidth for a 5000 TV line trispectral package would increase to 4 MHz. (Confer image orthicon.)

Scatterometer. (See Radar Scatterometer.)

Scintillometers. These devices are used to detect high frequency radiation, (gamma). As a remote sensing unit it will have to be confined to low flying aircraft since the attenuation of the naturally occurring low flux is large. (Unless you are interested in the extraterrestial influx.)

Scintillometers are used in prospecting for radioactive deposits. The device is electronically gated to look for frequencies associated with uranium and thorium. They may also be used in determining gross mineral classification (in conjunction with other data) and could be used for gross salinity changes in water areas by monitoring the naturally occurring potassium—40 count.

Gamma rays impinge upon an enclosed crystalline substance which causes a portion of it to glow (scintillate) very faintly. A photomultiplier tube detects and amplifies the flowing spots, which are then electronically displayed as counts per unit of time.

Spectroscopy. A general term—refers to the process of greatly expanding a region of the spectrum to look at specific frequencies, or at least at a smaller segment of the electromagnetic region.

THIR. (Temperature-humidity IR) This system is a dual thermistor bolometer—it requires 7 watts power—weighs 20 pounds and has data base bandwidths of 115 and 345 Hz/channel. One channel observes the water vapor in the atmosphere, and the other band, where the atmosphere is relatively clear (there is an assumption of 85% transmittance), looks at the temperature. Some correction can be made on the assumption by use of the water vapor band information. Clouds interfere with temperature measurements of surface features. Resolution is on the order of 4 or more square miles when measured from satellite altitudes. Temperature accuracy is poor. Temperature resolution is good. As with most temperature measurements, predawn-measurements are most useful.

APPENDIX 11

SPECTRAL USE CHART

This chart illustrates the electromagnetic phenomena of interest in remotely sensing earth resources along with the instruments or techniques which are currently used for this purpose. Also, the spectral regions of interest to several disciplines are shown along with the derived connection between the spectrum and its usefulness in solving certain major problem areas.

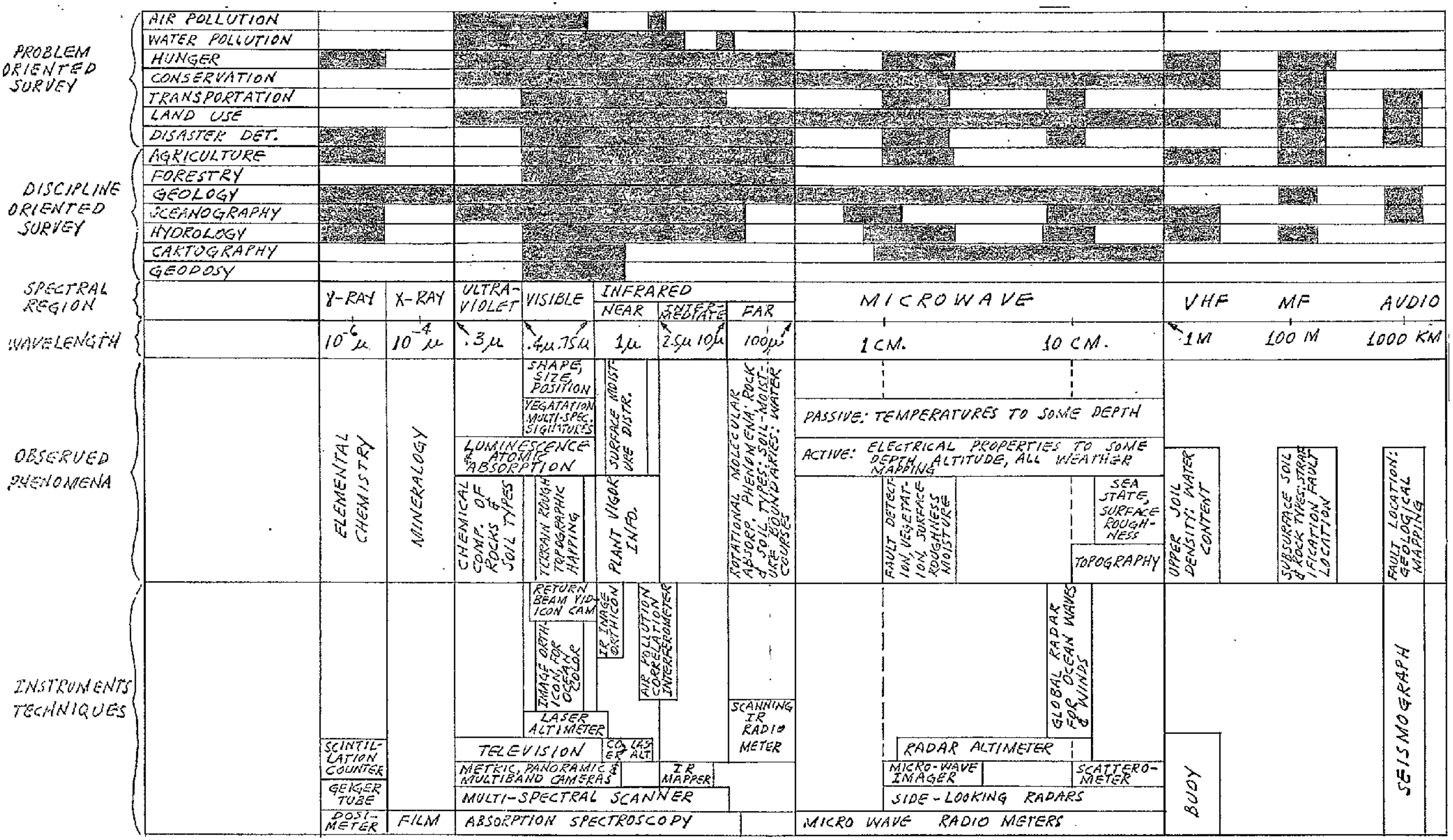


Fig. II Illustrating relation of radiation phenomena and associated sensors to the electromagnetic spectrum

FOLDOUT FRAME

FOLDOUT FRAME 2

APPENDIX III

THE MECHANISM OF SENSING VEGETATION

by

Paul A. Volz

Data collection on vegetation using airborne sensors currently has resolution of field or crop identification when assistance is given from ground truth. Improvements in sensors increase the necessity of learning what part of a crop radiates the return reflection pattern for plant identification and species separation. The mechanism of labeling is held in the morphology and physiology of the plant. As resolution improves, individual plants will be seen by distant aerial viewing. Knowing the features in plants contributing to vegetation separation as to plant type, age, growth vigor, and disease would enhance plant identification as remote sensing techniques improve. Plant texture, chemical and anatomical composition involve reflection characteristics responsible for aerial identification. The established discipline of plant anatomy nurtures agriculture and forestry sensing technology. Because a certain five-acre plot with a specific reflection pattern seen by satellite is identified as wheat does not guarantee all similar data will also represent wheat crops. Uninhabited and remote areas requiring ground truth studies before a timber stand can be identified as to species by satellite indicates an earth resource survey would not be economically sound or feasible. A near infrared spectrophotometer distinguishes a wheat field adjacent to corn, the plant spectrum entity producing the species identification must be learned for satellite data interpretation with a minimum amount of ground truth. If anatomical or physiological phenomena measure data variation, the morphology or chemistry of plants not yet aerially viewed could identify plant species, tensions, and life cycle stages by relating to spectral patterns, thus minimizing or even eliminating ground truth necessity.

Reflectance, transmittance, absorption, scattering, and other possible parameters, together produce the sensor pattern in identifying the plant canopy. Light reflectance and transmittance present a leaf canopy signature [1]. At present with the Gemini and Apollo missions, individual plants the size of trees or shrubs have not been discernible, instead only entire timber stands or rangeland ecotypes have been identified by photographic methods [4].

The leaf canopy is the object observed in aerial vegetation sensed by satellite. Leaf anatomy at present appears as the discipline subject to satellite sensor scrutiny with the moist cell wall outer surface of the spongy mesophyll emitting the reflectance pattern in near infrared spectrophotometry [5]. Infrared irradiation from leaves is a methodology suggested for ecological surveying [9], however, this brings to question how plants without spongy mesophyll cells and intercellular air spaces can be sensed, such as several succulents and evergreens. A mixed forest can be identified with current sensor technology, both decidious and evergreen species are present and accounted. A collection of leaf characteristics including anatomy and physiology would be more feasible as a species spectral configuration.

The problems of separating living cell layers of a leaf without disturbing cell anatomy and cell wall surface water are great indeed. To expose the spongy tissue by eliminating all other covering cells is difficult if all cells composing the palisade and spongy layers are parenchyma cells with similar structure and physiology. Each layer of cells in a leaf should be exposed to the surface for reflectance patterns without affecting the living tissue for correct sensor evaluation.

The belief of light reflectance and transmittance from green leaves at the cell wall - air interface of spongy mesophyll cell walls and intercellular spaces was proposed by Willstädder and Stoll in 1918. A more inclusive view is the consideration of identifying the total reflectance pattern as the diffusive characteristics of cell walls [19]. Near infrared spectral range of 750 to 1350 mu is affected by leaf structure [13, 16]. The most applicable spectral band for species identification and separation is near infrared.

Infiltration of leaves with water increases light transmission [17]. Cell walls are surrounded with an absorbed layer of water increasing leaf density in regard to sensor information. Cells, however, remain in their respective morphological patterns. The leaf salinity level would vary with environmental changes caused by the amount of water available to the plant and other physical entities. The plant species spectrum would relate to satellite sensors monitoring weather, soil and other ecosystem phenomena. All environmental data interrelates and changes, their associations and dependent effects must be learned for currect vegetation reflectance interpretation under a wide degree of enrivonmental variation. Any one species can vary in leaf anatomy in the thickness, presence or density of cells composing the palisade and spongy parenchyma. Form of the epidermis and vascular system also varies within one species producing differences in water content.

Internal cell structure including density and inclusive organelles bears study to sensor identification. Cells are vacuolated, and increased tonoplast volume occurs with maturation. Internal cell water as well as water outside the cell probably influences spectral patterns, a porous cell wall would not inhibit sensors from recording hydrologic information. If only water external to cells was sensed, a leaf canopy would be monitored primarily by only one cell layer, again eliminating the concept of internal spongy mesophyll leaf sensor recording. Authors have identified various wavelength reflectance patterns of leaves as being monitored by water and cellulose [17, 18], microfibril structure of cell walls [14], orientation of cell walls to the incident radiation [12], intercellular spaces and pigments within chloroplasts [7]. Infrared light is considered unaffected by chloroplasts [2], but salts cause physiological and morphological changes relating to light reflectance differences [3, 8, 10, 17]. Water or salinity stress causing stunting and cell morphology variation in leaves affects light reflectance patterns [6, 15, 16]. Infrared photography has been employed several years for ecological surveying and vegetation sensing [9].

Water in combination with the scatter controls the transmittance from a leaf [11]. Internal leaf structure including cell arrangement, intercellular air spaces, extracellular and tonoplast water, and cell organelles in combination control light scattering and the specific signatures of species. Further understanding of vegetation sensing should be learned to further accuracy in crop and species identification.

APPENDIX IV

JUSTIFICATION OF AN OPERATIONAL EARTH RESOURCES SURVEY SYSTEM

by

Hans G. Mueller

It is first of all necessary to define the meaning of "operational" in the context of an ERS system. The word is not listed in NASA's **Dictionary of Technical Terms for Aerospace Use**. In common desk dictionaries, such definitions as "able to function or to be used"[1] and "ready for or in condition to undertake a destined function."[2] From this one may infer that, for a system to be operational, it should function properly in the technical sense and, beyond this, achieve the objectives for which it was designed.

Concerning the case in question, the word operational probably implies that the system should be capable of furnishing information to users on a regular, or routine, basis. No suggestion is made that it must also be efficient, i.e., be able to extract the maximum sum of benefits from a given set of inputs. At any rate, efficiency in this sense can hardly pose a problem in this connection, since in regard to publicly-financed projects (ERS is assumed to be in this category) this type of performance cannot be measured, simply because there is no competition. A race or contest with one participant has no winner; there is no standard for evaluating the performance of the sole participant. The evaluation of efficiency not only takes account of the outlay with which a given objective was achieved but also of the entire array of alternative objectives which could have been not by the same outlay.

Commonality of Benefits

The situation is further complicated by the fact that public projects, with rare exceptions, are not designed to produce services of directly measurable value. What is the worth of flood prevention, early hurricane warnings, or the conservation of earth resources for generations not yet born? Even where some reasonable accurate estimates can be obtained as, for example, with respect to benefits accruing in the form of superior management of grazing lands, irrigation projects, and deep-sea fishing, the benefits are stated in terms of economized efforts or augmented harvests. The fallacy is then often committed of assigning dollar figures to these physical quantities by the use of "market" prices which are maintained only by means of government subsidies, with no regard to the true demand elasticities of the items involved or, in the fishing case, to the effect of increased harvests on future stocks. In the absence of policies which are complementary with these "benefits," the actual results may be quite different, namely, more unskilled farm labor moving into the slums of large cities, larger agricultural subsidies, and a reduction in the regenerative capacity, if not depletion, of certain fish species. These difficulties are probably of minor significance compared with those which may result in the international sphere. Some good will no doubt be generated by the global operation of the system. But problems may also arise, particularly in the form of suspicions and outright conflicts of interest. The net benefit-cost quotient may thus remain an imponderable long after the system will have become operational.

Project Justification and Politics

The preceding remarks should suffice to stress the point that the efficiency calculations of the business world, stated in terms of dollar cost/dollar benefit ratios, are not apt to be useful guides for the appropriation of public funds for specific projects. In the area of space exploration, the direction and momentum of this nation's efforts has in the past, been determined by the interaction of decisions made by the President, (as in the case of the Apollo program) Congressional Committees, and such departments or agencies as DOD and NASA. The

[1]The Random House Dictionary of the English Language, College Edition, 1968

[2]Webster's Seventh New Collegiate Dictionary, 1966

justification of the non-military space program was primarily the uplifting of American prestige, i.e., the country's reputation for technological excellence. Specifically, the goal was set to regain the leadership in this field. The method by which this was to be accomplished was the staging of spectacular events which would wrest the glory away from the Soviet Union. By dangling the promise of this feat before the eyes of Congress, it was possible to elicit appropriations of increasing, and by now very impressive, proportions.

The past method for justifiying significant space projects, with its reliance on spectaculars, may have set a pattern which will determine also the future trend of the American space program. Already, new goals are being propagandized in much the same vein as, for instance, the landing of a manned vehicle on Mars by the year 2000. In such an atmosphere of excitement, the advocates of an ERS program have little to present of equal glamor value (a photograph of The Salton Sea is no match for an astronaut on the moon). Indeed, Congress may even go so far as to require these advocates to justify their proposal by some kind of cost/benefit analysis. Their position would be then difficult no matter what standard is selected for the evaluation of the project: the profitability of private enterprise or social welfare criteria. On the one hand members of Congress will weigh the political goodwill generated from public expenditures in housing, education, feeding needy children, on the other a bundle of uncertain benefits ensuing from the implementation of a proposal bristling with esoteric notions.

Priorities of Human Needs: After Us the Deluge?

The choice is largely one between present and future needs.[1] Inview of the immediate needs of large groups of taxpayers, the perennial threat of inflation, and the short time horizon allowed for benefits in the political appropriations framework, it is not surprising that present needs rank high on the list of priorities. The problems arising from improper resource use are likely to become acute only at some future date. Measures to avert them are often taken in a haphazard manner or postponed altogether. After all, future generations do not vote or pay taxes. National governments are even more reluctant to make large financial sacrifices when the problem to be solved is not only one of the future but when in addition, it is common to several nations or to all mankind.

To be sure, some concern has been voiced recently about the need for the development of a system for the management of resources on a global scale. Studies have been made concerning the relation between population growth and the demand for resources. Findings about the predatory use of "free" inputs—air, water, open spaces, and recreation areas—have aroused the public interest in a number of countries. As a result, questions are being asked about the adequacy of national land-use laws and about the ability of present national and international institutions to assure the conservation of vital resources for the benefit of future generations. Although this campaign rarely achieved page one status in the newspapers, the realization gradually seems to have come that the margin for error in the management of resources, especially of those not traded in the market, (air, water, etc.) is becoming extremely narrow. It is also being recognized that this conclusion does not only hold for Belgium or the Ruhr area, but also for the United States (a country which closed its free-land frontier less than a century ago) and, in some respects, for the entire world.

The Role of Space Science Application

If it is true that the United States, and the world, will be confronted before long by a serious resource deficiency, it follows that a more intensive effort should be made for thwarting the hasty degradation of the environmental endowment. The health and welfare of future world inhabitants seems to be more worthy of consideration than the prestige effect ensuing from a televised landing on Mars (unless there is some proof that the planet affords a livable environment and that transportation costs will not exceed the budgetary limits of large numbers of prospective earth emigrants).

[1] Of course, an ERS system may also fill many information needs to increase welfare at the present time.

Given these assumptions, it also follows that a substantial segment of the gigantic American space effort should be made available to improve present methods of earth-resource management. Present legislation, arrangements, and methods in this area are often deficient because they are based on obsolete or insufficient information. Space science could therefore be assigned the important role of helping to provide both up-to-date and comprehensive information about vital elements in the human enrivonment. It will be necessary to obtain fairly precise data concerning both the stocks of available inputs and the rates at which the latter are consumed and, in some instances, regenerated. Only then can measures be taken to assure the continued availability of these inputs (by rationing their use or by improving their regenerative powers).

The characteristics of the needed information are as follows:

(1) coverage of most of the earth's land and sea area;

(2) comparability of data, i.e., data collected under uniform lighting, temporal, view-angle, etc., conditions;

(3) repetitive coverage to enable observers to measure rates of change in phenomena as well as variations of these rates;

(4) resolution must be sufficiently precise to permit the meaningful interpretation of the data collected.

At the present time, the only system that can provide information possessing the first three characteristics is one which utilizes satellite-based sensors. Aircraft systems do not have the ability to collect comparable data, repetitively, on an earth-spanning scale.

The Resolution Problem

The fourth characteristic, adequate resolution to satisfy some information needs, is of a more problematic nature. Although for some purposes resolutions better than 200 feet may be counterproductive, it appears likely that for other uses raw data must be more precise to yield benefits to society, possibly in the order of less than 50 feet resolution. There are several facets to this problem of required threshold resolution. In essence, they are linked to uncertainties in the areas of technology and politics.

Technological Constraints Given the present state-of-the-arts, the feasibility of obtaining high resolution data from an orbiting satellite is still in doubt. Limitations seem to exist concerning the overall weight of satellites, power capacity, antenna size, reliability of on-board data-storage equipment, and the workability of on-board computers for data reduction purposes. It may be questioned, however, whether any of these constraints are absolute in nature. Most likely, they are the outcome of a restrictive funding policy which denied capable enterprises and government agencies the necessary scope for fruitful research and development in these areas. With the proper financial impetus, technological constraints of the type mentioned could probably be dismantled within a period of three to four years.

A second constraint, the crowding of certain frequency bands for data transmission, is absolute in nature. It can only be resolved by the interaction and cooperation of competent national and international regulatory agencies.

Political Constraints A third, and rather vague, constraint is related to the political organization of mankind. The problems connected with it stem largely from the conflicting needs (real or imagined) of human society. They are, for the most part, quite unpredictable and may only evolve with the actual implementation of an operational ERS program. Existing institutions, traditions, and other arrangements all have the purpose to fill certain human needs. But the competing needs (including the need for prestige) of different groups often lead to social or political conflict, as one group strives to increase its own welfare at the expense of other groups or of all humanity. Moreover, spheres of influence tend to become departmentalized[1] to an extend which restricts the feedback of information concerning the effects of a given group's activities on the remainder of society and, ultimately, on the group itself. Because of this lack of communicative ability between groups or nations, the commonality of certain needs may go unrecognized and, conversely, conflicts based on little else but unfounded suspicions may arise. Again, these are admittedly only unforeseeable problems residing in the area of potential developments. It would, nevertheless, be brash to gloss over them entirely in the design of an ERS program on the assumption that they can be dealt with satisfactorily whenever they emerge. The possibility that existing institutions—political, legal, social, and economic—will limit or oppose the program must be seriously considered at the earliest stage of the effort.

On the domestic scene, conflicts of this type will probably prove manageable. The following situations are envisioned: (a) High-resolution data, harboring economically valuable information can either lead to a scramble among competing groups for the exploitation of a resource or, in the case the data are "leaked" to one group or individual, competitors are provoked into taking legal action against the ERS Administration, (b) A large company possessing well-equipped photography and imagery interpretation laboratories, recognizes, before anyone else, the economic benefits inherent in some of the data sold by ERSA at nominal prices. The company then proceeds to preempt the appropirate exploitation rights and thus reaps windfall gains, to a large extent at the taxpayers' expense. The rights may be acquired, possible through a number of assigned brokers, before the original owners were made aware of the increased value of their property.

The adoption of tight security measures at all levels of the ERS system—data acquisition, processing, and distribution—and, possibly, the granting of limited copyright protection in some cases (at a special fee) may avert most of these problems.

Greater difficulties are likely to be encountered in the sphere of international relations. Here not only proven wrong doing but more suspicions of foul play are apt to evoke emotional reactions on the part of nationalistic factions in some countries which, in turn, might impel the governments concerned to withhold cooperation with the ERS program or even to file formal protests with the government of the United States and with the United Nations against the overflight of their territory by ERS satellites. Sentiments might be aroused, for example, by the rumor that a large foreign-operated firm had the capability of interpreting data obtained from a satellite controlled by a foreign nation. The fact that the government of the firm's host country did not have this capability may lead the public of that nation to ascribe to the company an unfair vantage point in negotiations concerned with the extraction and sale of national resources.

Other nations might feel that the overflight of their territory by foreign-controlled earth observation satellites threatened their military security. From their viewpoint, the distinction between earth resource information and military intelligence may appear arbitrary or spurious. In fact, even the United States may become concerned with its own national security, should nations other than the Soviet Union, Great Britain, Japan, or EEC members, develop their own satellite-orbiting capability. Moreover, the possibility should not be discounted that within a few years some nations will develop systems which, by means of docking or outright destruction, can partially or completely eliminate the effectiveness of foreign satellites over the respective national territories.

Future international space law will no doubt evolve along the path broken by the scientific capabilities of nations. The 1967 Space Treaty amounts to little more than a "boy-scouts' honor" promise on the part of those active in the application of space science to

[1]The usual result is provincialism. It may be observed at almost all levels at which people associate, e.g., in international relations, at encounters between federal and state officials, in the interactions (or their absence) among departments of the federal government, in the relations between city government and city planners, and at universities. In fact, there is little evidence that even within agencies, such as NASA, a serious effort is made to solve problems by using the non-provincial (i.e., the interdisciplinary or expanded, society-directed systems design) approach.

refrain from developing space vehicles for aggression and to indemnify all parties for any damage caused by hardware impact on earth. The authors of this treaty were, of course, aware of the activities in which the leading two members of the "Space Club" were engaged. They probably harbored suspicions about the entirely peaceful nature of some of these activities. Nevertheless, the situation may have been considered to have developed into a stand-off between the two parties and it was not allowed to obstruct the dispatch of the treaty. This may change abruptly, as the membership of the club incrases, i.e., as space capabilities begin to proliferate. When this happens, the mere pledge by governments that their satellites are only designed for peaceful missions will hardly be universally accepted.

Even though the ERS system will represent only a fraction of the entire American space effort, it would be self-deceiving to initiate the operation on the assumption that all nations will either cooperate or acquiesce. Instead, a vigorous campaign should be launched to clarify all relevant issues at the outset, including the issue of anticipated improvements in data resolution. Negotiations should be opened both at the intergovernmental and the United Nations level. In other words, the planning for an ERS system should be as much the concern of the Departments of State and Justice as it has been up to now of another triad of Departments, namely, Interior, Agriculture, and Commerce. In particular, the impact of improved satellite-sensor resolution power on legal privacy and military security should be considered by all the parties involved and not remain a matter to be weighed only by officials from the Department of Defense and the National Aeronautics and Space Administration. *

A Note on the Role of Private Enterprise in an ERS Program

If earth resource sensing should yield pecuniary economic benefits, private enterprise should be allotted an important place in the application of this technology. The question arises then (apart from the possibility of international complications) whether there will be a role for competitive forces at any of the different vertical levels of the entire operation. Such a role would be justified, without sacrificing efficiency, whenever the optimum size of operations constituted only a fraction of the overall effort required. In other words, when duplication of a given activity does not increase total average costs. It remains to be determined, therefore, which of the manifold operations, from launching to data dissemination, can ultimately be expected to be of this type. The advantages of decentralized over centralized organization may be summariezed as follows: long-term planning, not subject to annual appropriations influenced by the vagaries of contemporary (and possibly ephemeral) political trends and groupings; dispersed and diversified initiative and decision origins—thus a reduced chance that important development opportunities will be overlooked; reduced chance of establishing one rigid organizational incentive for R & D (compared to the patent policy laid down in the 1958 Space Act). The following reservations may be listed about private enterprise participation: international legal complications,** joint costs of commercial and non-commercial outputs, potential conflicts between private and public benefits, and between domestic (USA) and foreign benefits, a vague boundary between private information gathering and military intelligence. Government participation in a "dedicated company" or the regulation of a public-utility enterprise by governmental agencies may obviate a few, but not all, of these difficulties. It would, at the same time eliminate most of the advantages expected from a competitive industry. Pure governmental organization offers the advantage that international conflict resolution becomes entirely an intergorvenmental affair which can, for the most part, be tackled outside the limits set by different sets of traditional civil law systems.

*In the Soviet Union, unlike in the United States, where private enterprise does not exist, "firms" may already be able to draw benefits from the use of high-resolution data obtained over that nation's vast area by the use of military intelligence satellites carrying powerful sensors of all types.

**For example, members of the Soviet bloc or less developed nations might object to the overflight of their areas by satellites controlled by companies or institutions whose legal status was recognized only by one or by a few western governments and whose ethics or intentions may be known only to a small private group of insiders.

Summary

The safe margin for error in the management of earth resources is likely to grow very narrow before the year 2000. For this reason, the maintenance of the earth's environmental endowment for generations not yet born should now, that doubts about this nation's excellence in space have been removed, merit a higher priority than the accomplishment of a manned mission to Mars. The role of space science in such an earth resource program would consist in furnishing national and international regulatory bodies with needed up-to-date and comprehensive information. Except for a number of constraints, a satellite-based resource survey and monitoring system appears to be ideally suited for this task. Two types of constraints are envisioned, technological and legal-political.

Technological constraints should be attenuated or removed by changing the funding emphasis of the American space program. The present, very timid, R & D approach in the earth resources area should be thoroughly revised. It might be substituted, for instance, by a crash program of a funding dimension measuring up to at least 25 percent of the scope now allowed for the Apollo program.

Legal and political issues, which are expected to arise from the implementation of an operational ERS system, should be recognized and, if possible, resolved. They are related to copyright questions, military security, and distrust among nations. Moreover, efforts should be redoubled to obviate problems which may emerge in the longer run as a consequence of the anticipated proliferation in the world of national space-use capabilities. Finally, the role of private enterprise in the application of space science should be reassessed and perhaps strengthened.

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